UNIVERSITY OF TASMANIA

ENCOURAGING UNDERSTANDING OF NATURAL RESOURCES USING EMERGENT TECHNOLOGY

Mark Terence Brown

BAppSci, MAppComp

HITLab AU,

School of Engineering and ICT

Submitted in fulfilment of the requirements for the Doctor of Philosophy

University of Tasmania, Oct 2015

Keywords

Author Keywords:

Natural Resources; Kinesthetic Learning; Multi-Touch; Geovisualization.

Interview Methods, Tangible User Interfaces

ACM Classification Keywords:

H.5.2. User Interfaces; H.5.1 Multimedia Information

General Terms:

Human Factors; Design.

Abstract

Dissemination and education of local natural resource issues is an ongoing priority for Natural Resource Management (NRM) and Environmental Agencies. However, with an ever-increasing amount of information competing for our time and attention, getting the message across is increasingly difficult. This project is an investigation of whether new emerging technology, such as touch tables, can help adults gain a better understanding of the nature of natural resource issues.

The hypothesis investigated was that *a tangible multi-touch table interface encouraged understanding of natural resource issues using map-based constructivist learning tasks*. The natural resource issue of *Preparing for bushfire* was chosen to test this hypothesis. It addressed key problems such as the low inclination by residents to prepare for bushfire. The system design and content evolved from participatory involvement of three bushfire community groups.

The table interface displayed local real world map information including online aerial photographs, property boundaries, building locations, elevation, fire history, and building defensive zones. The table interface system was designed for adults to complete short map-based interactive bushfire problem solving tasks using purpose-designed model objects: such as a house, chainsaw and a rake. The models worked seamlessly on the touch table providing immediate real-time feedback. The rake and chainsaw models operated similarly to their real-world counterparts. The chainsaw operated with short cutting movements, while the rake operated with sweeping motions, which allowed adults to physically play with scenarios in order to view the effects of real world natural resource interactions. The tangible table interface system was compared with the closest existing traditionally equivalent method using a within subjects exercise of 64 adult participants from the general public in situ at the local library and museum.

After using the *Preparing for bushfire* table interface all of the participants improved upon their pre-test scores indicating they learnt from the experience ($F(1)=13.01, p<0.001$). Comparative evaluation showed that the participants had a significantly greater learning gain from using the tangible table than the traditional method ($F(1)=13.01, p<0.001$). Furthermore, follow-up questions showed that 100% of

participants believed they learnt about *Preparing for bushfire* by using the table interface, and 70% felt motivated to undertake preparations for bushfire.

The original contribution to knowledge includes design rules for adult user preferences of topic choice, constructivist task design, interface object design, and object to surface operational functionality. These design rules were the guidelines behind the interface design that validated the hypothesis. Adult members of the general public improved their understanding of preparing for bushfire (the selected natural resource issue) by using a purpose designed tangible multi-touch table with custom physical models for constructivist learning tasks ($p<0.001$).

Further research should attempt to apply this method to expand the key messages presented for *Preparing for bushfire*, or evaluate this method for other natural resource issues.

Table of Contents

Keywords i
Abstract ii
Table of Contents iv
List of Figures xi
List of Tables xiv
List of Abbreviations xv
Declarations and Statements xvi
Declaration of Originality xvi
Declaration of Access xvi
Statement of Ethical Conduct xvi
Record of Publications xvii
Acknowledgements xviii

Chapter 1: **Introduction** 1
1.1 Introduction 1
1.2 Research purpose 1
1.3 Aim of the Research 4
1.4 Methodology 5
1.5 Outline of Chapters 6
1.6 Conclusion 7

Chapter 2: **Literature Review** 8
2.1 Introduction 8
2.2 Natural Resources 8
2.2.1 General Overview 8
2.2.2 Dynamics of Natural Resources 10
2.2.3 Importance of Understanding Dynamics of Natural Resources 10
2.2.4 Current Methods of Education and Information Dissemination to the General Public 12
2.3 Comprehension and Understanding 12
2.3.1 What is Comprehension? 12
2.3.2 Personalized Learning 14
2.3.3 Learning Styles 14
2.3.4 The Role of Kinesthetics in Learning 16

2.4 Interface Types for Natural Resources and Learning ... 18
2.4.1 Virtual Reality (VR) ... 19
2.4.2 Augmented Reality ... 20
2.4.3 Multi-Touch (MT) ... 22
2.4.4 Tangible User Interface (TUI) ... 25
2.4.5 Comparative Evaluation ... 27
2.4.6 Interface Types Suitable for all Learning Styles ... 30
2.4.7 Interface Suitability to Current Learning Methods ... 31
2.4.8 Interface Suitability to Dynamics of Natural Resource ... 31
2.4.9 Preferred System ... 32
2.5 Tangible User Interfaces ... 33
2.5.1 Tangible Object Nomenclature ... 33
2.5.2 Principles of Learning related to Tangible Interfaces ... 33
2.5.3 Learning through Collaboration ... 34
2.5.4 How Tangible Interfaces suit Personalised Learning ... 35
2.5.5 Do Tangible Interfaces Enhance Learning? ... 36
2.5.6 Knowledge Gaps in Hands-on Tangible Interaction Research ... 37
2.6 Interaction Design Characteristics ... 38
2.6.1 Interface Design ... 38
2.6.2 Interaction ... 41
2.6.3 IntePhysical – Digital Coupling ... 42
2.6.4 Representation ... 43
2.6.5 Tangible Objects may Replace Touch Functions ... 47
2.7 Natural Resource Considerations for TUI ... 48
2.8 Summary ... 51
Chapter 3: **Research Design ... 53**
3.1 Introduction ... 53
3.2 Hypothesis and Definition of Terms ... 53
3.3 Theoretical Framework ... 55
3.4 Methodology Overview ... 55
3.5 Research Design ... 56
3.5.1 Stage One ... 56
3.5.1.1 Semi-structured Interview of local experts ... 57
3.5.1.2 Participants for Stage One ... 58
3.5.1.3 Assessment - Questionnaire Design ... 59
3.5.1.4 Analysis ... 61

3.5.2 Stage Two 61
3.5.2.1 Suitable TUI Components to Encourage Adult Learning 64
3.5.2.2 User Studies including Pilot Testing of Underlying Concepts 65
3.5.2.3 Industry and Community Group Involvement 66
3.5.2.4 Participants for Stage Two 67
3.5.2.5 Assessment Methods - Questionnaire Design 68
3.5.2.6 Analysis 69
3.5.3 Stage Three 70
3.5.3.1 General Public Implementation of Natural Resource Tangible User Interface 71
3.5.3.2 Pilot Test of Full System 73
3.5.3.3 Participants for Stage 3 73
3.5.3.4 Assessment Methods 73
3.5.3.5 Analysis 77
3.6 Limitations 81
3.6.1 Participant Limitations – Characteristic Traits of the General Public 81
3.7 Summary 82
Chapter 4: **System Design and Development 83**
4.1 Introduction 83
4.2 Contribution to the Research from Stages One 84
4.3 Justification for Choice of Application Topic of Preparing for Bushfire.. 85
4.4 *Around the World* Exercise to Evaluate Fundamental Concepts 88
4.5 Programming Environment 94
4.5.1 Operational Logistics of the "preparing for bushfire" Interface 94
4.6 Tangible Interface Design 95
4.6.1 Components of TUI 95
4.6.2 Effective Physical – Digital Coupling 96
4.6.3 Tangible Object Design Guidelines 96
4.6.4 Design Considerations for a Collaborative Interface 99
4.6.5 Novelty Avoidance 100
4.7 Action Research Experience 100
4.7.1 Participatory Research 101
4.7.1.1 Representational Balance within the Participatory Research 102
4.7.1.2 Lilydale 103
4.7.1.3 Lorinna 105
4.7.1.4 Ferntree 108
4.7.1.5 Working with Industry – TFS and State Fire Management Council 110
4.7.2 Contribution to the Research from Participatory Research 111

4.8 Bushfire Application Development and Preliminary Deployment 112
4.8.1 Pilot Deployment of General Public Version at Kingston Shopping Centre 112
4.8.2 Lessons Learnt from the Kingston Experience 114
4.8.3 Design of the *Preparing for Bushfire* Interface 116
4.8.4 Animating the Impact of Bushfire Preparations 118
4.9 Design of Map-based Constructivist Exercises using Tangible Objects .120
4.10 Traditionally Available Alternative 131
4.11 Summary 132
Chapter 5: **Experiment Implementation 134**
5.1 Introduction 134
5.2 Experiment Structure, Implementation and Deployment 134
5.2.1 Avoiding Bias by Changing the Sequence 139
5.3 The Design of the Response Questionnaire 139
5.4 Deployment 147
5.5 Summary 148
Chapter 6: **Results 149**
6.1 Introduction 149
6.2 *Preparing for Bushfire* for General Public Spaces Exercise 149
6.3 Summary of Participants 150
6.4 Predisposition to Bushfire Risk 150
6.5 Perception of Prior Knowledge and Understanding of *Preparing for Bushfire* 151
6.6 Test for Presence of Learning 152
6.7 Learning Gains – Change in Understanding of *Preparing for Bushfire* ...155
6.7.1 Contribution of the Test Order and Worked Examples 156
6.8 Contribution from Constructivist Learning Tasks 158
6.8.1 Examples of Completed Worked Examples and Practical Exercises....... 159
6.8.1.1 Worked Example Scenario 2 159
6.8.1.2 Worked Example Scenario 5 160
6.8.1.3 Practical Example Scenario 2 161
6.8.1.4 Practical Example Scenario 3 162
6.8.1.5 Practical Example Scenario 4 163
6.8.2 Contribution to Test Scores and Learning Gain by the Tangible Objects 163
6.8.3 Itemisation of the Overall Time taken to Complete the Exercise 165

6.8.4 Relationship between Tests and Time spent on the Constructivist Tasks 166
6.9 Contribution of Prior Knowledge to Test Scores 167
6.10 Groups Vs Individuals 168
6.11 Model of Factors Contributing to Test Scores and Learning Gain 169
6.11.1 Multiple Regression Model Assumptions 170
6.11.2 Model Results 171
6.12 Perception of Occurrence of Learning 172
6.13 Perceived Contribution to Understanding from Features of the Interface 173
6.14 Engagement and Flow 173
6.15 Benefits of Map-based Traits of the Interface 174
6.16 Familiarity with Touch 175
6.17 Summary 175
Chapter 7: **Interpretation and Discussion 177**
7.1 Introduction 177
7.2 Hypothesis and Theoretical Framework 177
7.3 Overview of the Significant Finds of the Study 178
7.4 Exploring Encouragement of Understanding 179
7.4.1 Test for Presence of Learning 179
7.4.2 Highest Learning Gain 179
7.4.2.1 Low learning gain aberration 183
7.4.3 Contribution from Map-based Constructivist Learning Tasks 185
7.4.3.1 Cognitive load 187
7.4.3.2 Object influence on Results 188
7.4.3.3 Comparison between Tests and Time spent on the Constructivist Tasks 189
7.4.4 Learning through Collaboration 190
7.4.5 Contribution of Engagement 192
7.4.6 Predisposition to Bushfire 194
7.4.7 Perception of the Occurrence of Learning 195
7.4.8 Perception of Pre-existing Knowledge of *Preparing for Bushfire* 195
7.5 Participants 196
7.6 Familiarity of Touch 197
7.7 Answering the Research Question 198
7.8 Limitations to the Study 200
7.8.1 Internal Confounders 200

7.8.1.1 The Instructor 200
7.8.1.2 Non-sharing of Tangible Interface Tools 201
7.8.1.3 Interface Objects behave as Prompts 201
7.8.1.4 Guessing Answers on the Pre-test 202
7.8.2 External Confounders 203
7.8.2.1 Active ongoing Promotion of Bushfire Education 203
7.8.2.2 Object Design limitations 203
7.8.3 Contribution from Interactivity 203
7.8.4 Retention of Understanding and Motivation 204
7.8.5 Technical Design Issue of Touch on Microsoft PixelSense 204
7.9 Future Work 205
7.9.1 Extend the Comparative Study to include a Multi-touch only Interface 205
7.9.2 TFS Implementation of a Cheaper Budget System 206
7.9.3 Recommendations for TFS - Clear around Shed 206
7.10 Summary 207
Chapter 8: **Conclusion 208**
8.1 Introduction 208
8.2 Research Purpose 208
8.3 Response Addressing the Hypothesis 209
8.3.1 Research Question One 210
8.3.2 Research Question Two 211
8.4 Validity of the Method 212
8.4.1 Repeatability 212
8.4.2 Premise 212
8.4.3 Application Topic 212
8.4.4 Testing and Evaluation 213
8.4.5 Founded on Established Methods 213
8.5 Contribution to Knowledge 213
8.6 Limitations 214
8.7 Future Work 214
8.8 Conclusion 215
Appendix 1 – Stages One and Two Results and Discussion 216
A1 Stage One Results and Discussion 216
A1.1 Results and Discussion 216
A2 Stage Two - Results and Discussion 222
A2.3 Tangible Object Creation 222

Appendix 2 - Lilydale Bushfire Preparedness Education Meeting Summary 225

and Results 225

Appendix 3 - Lorinna Bushfire Preparedness Education Meeting.............230

Summary and Results 230

Appendix 4 - Ferntree Bushfire Preparedness Education Meeting............235

Summary and Results 235

Appendix 5 - Meeting with Community Protection Planning and State Fire 238

Management Council Hobart..238

Appendix 6 - General Public Pilot Exercise at Kingston Running Script ..241

Appendix 7 – Questionnaire for General Public Trial 244

at Kingston Shopping Centre..244

Appendix 8 – Letter of Support from Kingborough Council.........................254

Appendix 9– Questionnaire for Full General Public Exercise 255

Bibliography 262

List of Figures

Figure 1: Moreton Bay Waterways and Catchment Partnership Report Card....................3
Figure 2: Blooms Revised Taxonomy(Queensland/Education 2010)................................13
Figure 3 VRFIRE - at the fire boundary (shown in red) (Sherman et al., 2007)................19
Figure 4: First down line in Gridiron(HowStuffWorks 2012)..21
Figure 5 SEA LAB Augmented Reality Eco-education for Pollutants..................................22
Figure 6 User Interface Design of Futura - Sustainability Futures Game (Antle et al., 2011a)..........23
Figure 7: Illuminating Clay showing landform analysis (Piper et al., 2002)......................26
Figure 8: Tangible and virtual jigsaw puzzle (Xie & Antle, 2008)......................................28
Figure 9: Analytic framework on tangibles for learning [Marshall, 2007].........................36
Figure 10: The ReacTable, a musical instrument controlled by tangible objects.............42
Figure 11: Using a standard children's paintbrush with a drawing application on the PixelSense..........47
Figure 12: The TangiTable in action...49
Figure 13: The setup of the GeoTUI sytem..50
Figure 14: Tasmanian Organisations involved with Natural Resources............................59
Figure 15: Usability matrix in the user response questionnaire for the *Around the World* exercise..........69
Figure 16: The within subjects design for the evaluation...72
Figure 17: The practical component section of the test...75
Figure 18: These practical scenarios are presented in the interim......................................76
Figure 19: The sets of tangible objects for the *Around the World* exercise.......................90
Figure 20: The 2 sets of interface buttons for the *Around the World* exercise...................90
Figure 21: The model of the Eiffel Tower (gold) sitting on top of the digital display of its real world location in Paris..........91
Figure 22: Frequency of use of interface elements showing one standard deviation as error bar..........92
Figure 23: The PixelSense will *programmatically recognise any object that has a Microsoft Tag attached.*..........94
Figure 24: The BRAM Likelihood modelled map layer..102
Figure 25: Location of bio-risk communities...103
Figure 26: Location Map for Lilydale properties...104

Figure 27: TasFire presenters using the tangible touch table interface 104
Figure 28: The only road into and out of Lorinna. 105
Figure 29: Bushfire Ready Neighborhoods meeting 106
Figure 30: The interface for Lorinna showing the property boundaries and contours. 106
Figure 31: Houses in the Ferntree area near Hobart. 108
Figure 32: Typical vegetation surrounding houses in Ferntree. 109
Figure 33: The opening night at the Kingston shopping centre 112
Figure 34: Peri-urban properties, indicated in yellow 115
Figure 35: The tangible touch table interface for the *Preparing for Bushfire* exercise. 117
Figure 36: The result after the rake and chainsaw have been used 119
Figure 37: The interface tangible objects. 120
Figure 38: The house interface object placed upon the surface 121
Figure 39: The solution for a task scenario 123
Figure 40: Practical test set 1 showing the map images for each scenario. 126
Figure 41: Practical test set 2 showing the map images for each scenario. 127
Figure 42: Worked examples set 1. 129
Figure 43: Worked examples set 2. 130
Figure 44: The tangible touch table in action with the house active on the interface. . 131
Figure 45: The within subjects design for the evaluation. 134
Figure 46: Interactive Table in situ at Launceston LINC. 150
Figure 47: Responses for Q6 How well informed do you consider yourself 151
Figure 48: Test scores for participants of the Interactive Table--> Static Map sequence 153
Figure 49: Test scores of the Interactive Table--> Static Map sequence 153
Figure 50: Test scores for participants of the Static Map --> Interactive Table sequence 154
Figure 51: Group pairs of Interim learning gains with significantly different means .. 157
Figure 52: Group pairs of Final learning gains with significantly different means 157
Figure 53: A community example of a Bowls Club. 160
Figure 54: Worked example of a property on the edge of town neighbouring 160
Figure 55: A house surrounded by trees on a standard size block. 161
Figure 56: A house on the side of a hill surrounded by trees 162
Figure 57: A house at the bottom of a hill with a tree lined driveway. 163
Figure 58: test scores vs participant's perception of understanding 167
Figure 59: Distribution of participants between groups and individuals 168

Figure 60: test scores and learning gains for Group members and Individuals. 168
Figure 61: Learning Gain broken down by contribution from methods. 180
Figure 62: Learning gains between the tests. 180
Figure 63: Test scores for participants of the Interactive Table--> Static Map sequence 183
Figure 64: Tangible objects of the *Preparing for Bushfire* Interface - Rake, House and Chainsaw. 202
Figure 65: Lack of understanding of the interconnectedness of natural resources 217
Figure 66: To what degree do you believe that the general community understands. 218
Figure 67: On-ground extent of the natural resource issues identified in the survey.. 219
Figure 68: Tangible model objects from the *Around the World* exercise. 223
Figure 69: 3d printed tangible objects. 224
Figure 70: Location Map for Lilydale Properties involved in Community Consultation 225
Figure 71: TasFire Bushfire Preparedness Training at Lilydale Fire Station 226
Figure 72: Screen image of the touch table showing BRAM at state scale....................... 227
Figure 73: Lorinna region bushfire preparedness pilot area. 230
Figure 74: The only road into and out of Lorinna 231
Figure 75: Ferntree WestRinga Road bushfire preparedness Group 235

List of Tables

Table 1: Main natural resource issues 84
Table 2: Means of user perception using a 1-5 rating with 5 being best 93
Table 3: Components of TUI from empirical studies. 95
Table 4: TFS bushfire education materials 113
Table 5: Responses from Kingston participants for the adult learning questions. 113
Table 6: Properties used for the practical exercises. 124
Table 7: Properties used for the worked examples. 128
Table 8: The implementation procedure for the experiment with the general public. 135
Table 9: There are 8 combinations of exercise elements 139
Table 10: Predisposition to bushfire risk. 151
Table 11: Paired-T statistics comparing test scores 152
Table 12: Paired-T statistics comparing test scores for participants 154
Table 13: Learning gain improvement in test scores. 155
Table 14: Learning gains improvement in test scores for each unique group 156
Table 15: Regression analysis investigating relationship 164
Table 16: Time taken (mins) in each section of the general public experiment. 165
Table 17: The time spent on the worked examples and on the tests 166
Table 18: Regression analysis investigating relationship between *Time* 167
Table 19: Multiple Regression Analysis investigating relationship between both *Time* 171
Table 20: The perception of the contribution that each aspect of the experience made 173
Table 21: Engagement of the table interface features. 174
Table 22: Contribution of the Interface Map-based traits. 174
Table 23: Comparison between *Preparing for Bushfire* exercise and the most similar study 181
Table 24: Urban Sprawl natural resource issue 210
Table 25: Main natural resource issues 218
Table 26: Urban Sprawl 221

List of Abbreviations

AR	Augmented Reality
BRAM	Bushfire Risk Assessment Methodology
DPIPWE	Department of Primary Industries, Water and Environment
GIS	Geographic Information System
GUI	Graphical User Interface
HCI	Human Computer Interaction
NSP	Nearer Safer Places
TFS	Tasmanian Fire Service
TUI	Tangible User Interface
3d	Three dimensional

Declarations and Statements

Declaration of Originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright

Declaration of Access

This thesis may be made available for loan and limited copying and communication in accordance with the Copyright Act 1968.

Statement of Ethical Conduct

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

Signed **Date** 4/11/2015

Record of Publications

Brown, M., Chinthammit, W., Nixon, P. (2013). What are the Issues with Natural Resources? How can Emerging Interactive Technology Help? In Proceedings of the Spatial Sciences & Surveying Conference 2013 – SSSC2013

Brown, M., Chinthammit, W., Nixon, P. (2013) Using Tangible Objects with Interaction Technologies to Promote Better Understanding. Tasmanian State Spatial Sciences & Surveying Conference 2013 - SSSI2013

"Preparing for Bushfire." The Science Show Presented by Robyn Williams. ABC Radio National. Saturday 6 December 2014 12:23PM. Radio. Available at: http://www.abc.net.au/radionational/programs/scienceshow/preparing-for-bushfire/5947968

Brown, M., Chinthammit, W., Nixon, P. (2014) A Comparison of User Preferences for Tangible Objects vs Touch Buttons with a Map-based Tabletop Application In Proceedings of the 26th Australian Computer-Human Interaction Conference -OzCHI ’14

Acknowledgements

I would like to acknowledge NRM North for providing the scholarship to undertake the PhD research.

First and foremost I would like to acknowledge my supervisors from the University of Tasmania. I offer my sincere thanks and appreciation to DVC Prof Paddy Nixon and Dr Winyu Chinthammit for their most welcome assistance, encouragement and patience during the four years of my PhD.

I would like to thank Peter Middleton of the Tasmanian Fire Service for his great assistance. I would like to thank the members of the Tasmanian Fire Service Community Education team: Dave Cleaver, Suzette Harrison, and Lesley King.

Thank you members of the following Bushfire Ready Neighbourhoods Community Groups for letting me attend meetings, answering my questions, and providing me with such useful feedback:

- Lilydale Mountain Road,
- Lorinna, and
- Ferntree Westringa Road,

I would like to extend my grateful thanks to Kingborough Council for hosting me for a week at the Kingston Shopping Centre, and I would like to thank Donovan Burton Climate Adaptation Specialist for organizing the experience.

Similarly I would like to acknowledge my appreciation to Lou Foley for organizing my stay at Launceston LINC. Accordingly, I would like to thank the Launceston LINC itself for hosting me for a week while I conduced the exercise. Likewise, I would like to thank the Innovation Circle at the Launceston Museum and Art Gallery and their motley crew.

A big thank you to the budding supervisors: Dr Robert Rowe and Dr Matthew Springer.
Thank you to fellow PhD students: Simon Stannus and Steve Neale; for the games of table tennis - It was about the only exercise I got.

I would like to thank those who took the time to proof read my chapters Susan Brown, Denice Gaughwin, and Julian Orbach, as well as Mai Frandsen for her early assistance,

I will not forget how grateful I am to Andrew Spilling for his tireless support.

Lastly, but not least, the biggest of thank yous go to my loving wife Felicity and my children: Alixandra, Joshua, Benjamin and Lawson. I would like to apologise for not spending as much time with you as you and I would have liked during the last few years.

Chapter 1: **Introduction**

"The educated person is one who knows how to find out what he does not know"
— George Simmel

1.1 Introduction

This chapter is a brief overview of the research. It explains the initial motivation along with the aims and the hypothesis. This is followed by the research design which is briefly explained. The chapter finishes with a synopsis of the thesis presented as an outline of the chapters.

1.2 Research purpose

In 2012 it was predicted that 2012–2013 would be the first year that the world did not produce enough food to feed everyone on the planet (Lagi et al., 2012). This anomaly was blamed mainly on extreme weather conditions on several continents (Lagi et al., 2012). However, although the food shortage did not eventuate, it is generally anticipated that at some point in the future the steadily increasing, and longer living population, will exceed the world's feeding capacity. Yet, houses are built on quality cropping land, while the shrinking pool of remaining farmland is left to support the increasing load. As the Living Planet report for 2014 asserts "*A range of indicators reflecting humanity's heavy demand upon the planet shows that we are using nature's gifts as if we had more than just one Earth at our disposal.*"(McLellan (eds) 2014, p. 4). This points to a need to use Earth's resources more effectively.

One approach is to improve understanding of the interconnectivity of natural resources, specifically how changes in one natural resource affect other natural resources in direct and sometimes unique and unexpected ways. Such an understanding will contribute to improving current use and to mitigating inadvertent detrimental environmental impacts (García-Barrios et al. 2008).

Although people of all ages make choices that impact the environment, from household water use to fishing, it is the adults whose choices have the significantly larger scale impact. Adults make the purchase choices; work in the companies; manage projects, and coordinate the family lifestyle. Therefore, the research strategy is to encourage a better understanding of natural resources with adults as the target audience.

Dissemination and education of local natural resource issues is an ongoing priority for Natural Resource Management (NRM) and Environmental Agencies, who actively apply a wide range of methods to raise awareness to the general public. Unfortunately, the existing systems are only partially successful and do not guarantee that the information presented is even read, let alone understood.

Furthermore, these dissemination methods may be hampered because of difficulties with comprehension. The natural resource community has a perception that the general public have a poor understanding of the flow on effects of natural resource issues. Specifically, how changes in one natural resource affects other natural resources in unique and unexpected ways.

Two case studies are presented as examples of decisions that impact the natural resources and the environment. The first is an example of an environmental disaster directly caused by human decision making that failed to appreciate the variability and dynamics of natural resources. It is representative of similar man-made disasters.

A well-known international example is the collapse of the Northern Canadian Cod industry in 1992. The collapse was a catastrophic economic loss, as well as having a devastating long term ecological impact (Lindenmayer & CSIRO 2007). Cod fishing at the Grand Banks commenced in the 1600's with European ships routinely fishing the region. Cod fishing peaked in the 1970's, then again in the late 1980's, until the Canadian government placed a moratorium on cod fishing in the region. Fishing catches were 60% of the estimated cod population at the time of the moratorium, while the annual fish catch was set at 16% of the cod population. The ecology of the region was deemed to be irreversibly destroyed and the economic impact was the loss of 35 000 local jobs. The business sector successfully applied pressure on the government to increase the catch, arguing that the method used to calculate the cod population underestimated the actual population. Meanwhile, hindsight shows that the scientists were unable to accurately predict the population size because of 'naturally high levels of variability in the population due to dynamic environmental factors' (Hutchings 1996).

The following is a positive example of a balanced and well managed system that demonstrates effective allowance for the interconnectedness of natural resources. Their dynamic nature is captured by real-time sensors which are used to manage the region.

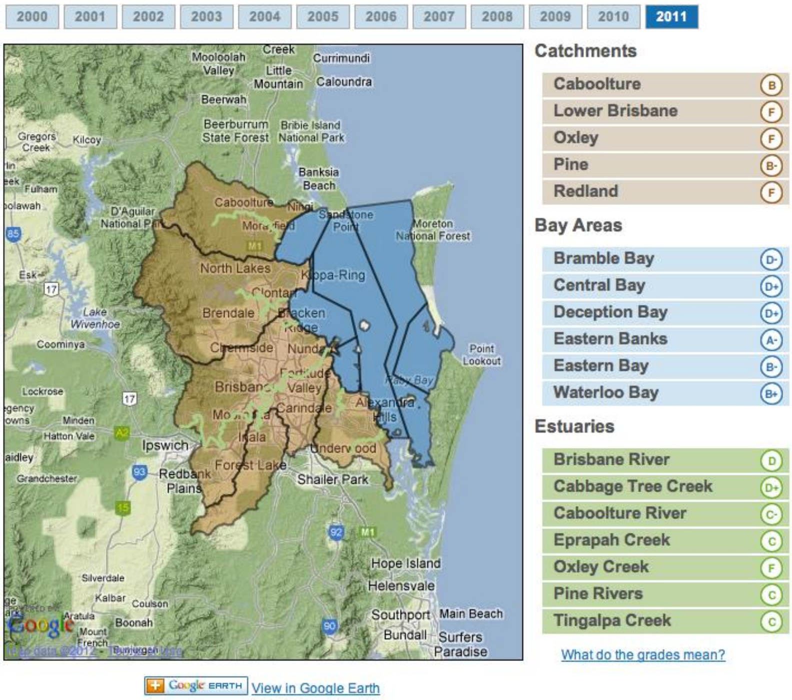


Figure 1: Moreton Bay Waterways and Catchment Partnership Report Card

South East Queensland is the second fastest population growth region in Australia. The 2010 Census states the population as 3 million people with growth of 13% per year. This region is home to 14 river catchments and Moreton Bay. Moreton Bay is internationally recognised for its biodiversity, with extensive areas of mangroves, seagrass, shellfish, diverse fish species, and sea turtles (Lindenmayer & CSIRO 2007). Meanwhile, it is home to a major shipping lane and commercial fisheries. The Moreton Bay Waterways and Catchment Partnership was established to manage and monitor the ecosystem health, to maintain the balance with the commercial, recreational and urban uses, with increased population pressure and climate changes (Lindenmayer & CSIRO 2007). The partnership assesses the monthly measurements from hundreds of monitoring sites throughout the region, identifying issues, implementing remediation programs and publishing annual results as an environmental report card (Lindenmayer & CSIRO 2007), refer Figure 1.

Since implementation, the health of the region has improved and the program is considered a success.

This research thesis is an investigation of whether new emerging technology, such as Augmented Reality (AR), Virtual Reality (VR), Multi-touch (MT), or Tangible User Interfaces (TUI), can help adults gain a better understanding of the nature of natural resource issues.

1.3 Aim of the Research

The overarching aim of this research is to improve understanding of natural resources so that natural resources are considered as part of decision making processes. The education process aims to inspire and motivate adults to consider the impacts of their decisions with regard to flow on effects to natural resources. It is expected that emerging technology can contribute to this aim by being effective at improving the understanding of natural resources of adult members of the general public.

The major considerations to address the problem are related to:

- how adults prefer to learn,
- adult learning methods,
- how to convey natural resources information,
- emerging technology and their usage,
- what are the methods that underpin these criteria, and
- how to effectively communicate through the new technology medium.

The literature review along with the spatial nature of natural resources and the preferred learning mechanisms for adults, indicate that an Interactive Map-based tangible touch system using constructivist leaning tasks could ideally suit the research goal.

The hypothesis for this thesis is:

A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources

This hypothesis contains the following research questions:

1. *What is required for comprehension of dynamics of natural resources?*

2. *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

1.4 Methodology

The research uses a design research methodology refined by participatory action research with industry and established community groups (Starcic et al. 2013). These stages were implemented sequentially. The results are measured using a mixed methods approach (Oates 2006).

The research is undertaken in three stages:

1. The first stage was a semi-structured interview of natural resource experts designed to obtain information to help answer the first research question *What is required for comprehension of dynamics of natural resources?*
2. Stage two evaluated elements of TUI interactive technologies to identify components most suited for the research purpose. This search concentrates on components with the most potential for adult learning with natural resources. It was followed by a trial of preliminary implementations evaluating suitability, usability and engagement for the appeal of detailed design characteristics to the general public adult subjects.

   The second part of stage two advanced the design of the final application by consultation with industry and community groups (people directly affected by the natural resource issue) to incrementally refine learning requirements, priorities and implementation methods.
3. The last stage was to conduct user testing to evaluate the features of a purpose developed natural resource user interface that specifically incorporated optimal design characteristics. The results answer the second question: *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

1.5 Outline of Chapters

This section contains an overview of the seven remaining chapters in this thesis.

The next chapter is the Literature Review which examines empirical and theoretical studies related to emerging technology, adult learning, including sample natural resource applications using different styles of emerging technology. The most appropriate technology is identified (Tangible User Interfaces (TUI)), then evaluated by review of its major styles, frameworks, and functions as they relate to adult learning or interface design. The chapter finishes by presenting the hypothesis.

The third chapter is the Research Design which explains the plan for the methodology for a solution to the research questions. It discusses the merits of adopting a three stage design. The overall mixed methods approach is discussed, justifying the semi-structured interviews of experts in stage one, along with the measures and user studies of tangible user interface factors from the second stage. The analysis, measures and data capture techniques of the within subjects comparative study in the third stage are explained as an overview. This includes a preview of the structure of the pre-test, interim test, and post-test.

The fourth chapter is the System Design and Development. This sizeable chapter explains the design and operation of the user interface for the Tangible User Interface touch table. It also explains the detailed design and operation of the map-based constructivist tasks. The rationale behind both designs is presented with reference to literature. The reasons why *Preparing for Bushfire* is chosen as the application topic is explored, and the traditionally available alternative is defined. The outcomes from the participatory involvement of three bushfire community groups is reported, along with the contributing outcomes from stage one and stage two.

The fifth chapter is the Experiment Design. It contains the detailed implementation procedures, along with the 47 question assessment questionnaire. The rationale and analysis for each question, or question group, is discussed. Locations to deploy the exercise are evaluated.

The sixth chapter is the Results chapter. The Results chapter only contains results from the third stage. This is because stage three produces the answer to the hypothesis and research question. Discussion and Results for stages one and two are available in Appendix 1. The results show any learning gain, or improvement in test scores. A multiple regression model of the *factors contributing to test scores and learning gain* is run within the R statistics package. The model identifies which parts of the experiment have a significant influence upon test scores or learning gain. The review questionnaire is assessed, and the session audio logs are reviewed for qualitative analysis within the NVivo statistical package.

The seventh chapter is the Interpretation and Discussion chapter. The answer to the research question is presented and explained. The contributing factors to the test score and learning gain are examined. Limitations are discussed, and avenues for future work are disclosed.

The final chapter is the Conclusion which presents the response to the hypothesis with the answer to the research question. Other notable results are discussed, and recommendations for future work are presented.

1.6 Conclusion

This chapter introduced the problem of effective communication and dissemination of natural resource issues. Emerging technology seems admirably suited for this purpose as it offers engaging new techniques with the potential to demonstrate the complexity of natural resource interactions in an engaging, informative and memorable manner.

Chapter 2: **Literature Review**

'The major problems in the world are the result of the difference between how nature works and the way people think'

- Gregory Bateson

2.1 Introduction

The review begins by considering natural resources focusing upon how adults communicate and understand natural resource issues. This thesis is premised on effectiveness of communication of natural resource issues and challenges specifically that the general public do not have an adequate understanding of natural resources, hence make decisions that detrimentally impact the environment.

This chapter will present well known examples of poor understanding and their consequences. It will discuss current methods of education and information dissemination, touching on their deficiencies. It will move on to approaches for learning, highlighting those suited for this research purpose.

Emerging technology is considered as a solution whereupon it is defined then evaluated by critiquing the different applications of several types. The different technology types are compared where it is argued that Tangible User Interfaces (TUI) offer the most suitable approach. The chapter finishes by highlighting the benefits of specific styles of TUI to the spatial nature of natural resource information and to learning styles of adults.

2.2 Natural Resources

2.2.1 General Overview

Natural resources sustain all life on the planet (McLellan (eds) 2014). They are the fundamental elements of nature: water, air, sunlight, plants, animals and minerals (Dahlman & Renwick 2015). We use and consume resources to live, work and play. They are as essential to our well-being as we are to their integrity and in this sense humans are the custodians of the environment (Di Vita 2006).

This custodianship is the legacy of our descendants. Future generations will need sufficient resources to feed the ever growing and longer living population (Lagi et al. 2012). Some resources occur all around, such as air and sunlight. These ubiquitous versatile resources are constantly replenished (Dahlman & Renwick 2015). However, this is not the case for most natural resources, as they are limited by the manner in which they are created. 'A natural resource is often characterized by amounts of biodiversity and geodiversity existent in various ecosystems.' (Natural Resource Information 2011). A non-renewable resource is considered to be a resource that is consumed at a greater rate than it is replenished (World Commission 1987). These natural resources are located in clusters where the past or present environmental conditions suit the creation of the resource. Inorganic natural resources, such as minerals and oil, occur where the environmental conditions were suitable for the natural resource at the time of their creation (Dahlman & Renwick 2015). Living natural resources rely on other living natural resources (plants, microorganisms, prey animals) to survive. Even artificial products are created from natural resources.

Man-made products may be made from renewable resources, non-renewable resources, or combination of the two. Whenever humans make anything, it consumes natural resources and impacts the environment by the extraction process, construction process and the method of utilisation and disposal of the item.

Although people of all ages make choices that impact the environment, from household water use to fishing, it is the adults whose choices have the significantly larger scale impact. Adults make the purchasing choices; work in the companies; and coordinate the family lifestyle. All of these have impact upon the natural resources. The values of the ecological footprint (a measure of the biological resources required to replace resources consumed) show that first world countries consume more resources than can be replaced by one Earth (Marvell 2002). This measure is exacerbated by any actions that are detrimental to natural resources. Implementing strategies to reduce negative impacts to natural resources will improve overall outcomes for natural resources. One strategy is to develop a better understanding by adults of natural resources, their availability, the impact of choices and their consumption.

A perception exists amongst the natural resource community that the general public have a poor understanding of the flow on effects of natural resource issues. Specifically, how changes in one natural resource affect other natural resources in unique and unexpected ways. The lack of such an understanding leads to detrimental impacts on the environment (García-Barrios et al. 2008).

2.2.2 Dynamics of Natural Resources

The process by which one natural resource depends upon another is a fundamental economic concept known as *interconnectedness* (Cudmore 2009). 'The existence of interconnectedness explains why when changes are made in one part of the ecosystem, other components are affected, often in unexpected ways' (Cudmore 2009, p5). The term interconnectedness will be used interchangeably with dynamics in this thesis, meaning that the *interconnectedness of natural resources* is equivalent to the *dynamics of natural resources*. Interactions define the interconnectedness between natural resources. They determine how one resource affects another resource, or affects several resources. At a cursory level, these interactions are often an obvious direct relationship, such as the influence that ready access to water has to aid the growth of plants. But sometimes the interactions are not obvious; in the case of groundwater, which is affected by geology, soil water holding capacity, water recharge, ground cover, water use, micro-channels, nutrients and salinity. Understanding the influence that a change in a natural resource has on one or more natural resources helps to develop comprehension of the dynamics of natural resources.

2.2.3 Importance of Understanding Dynamics of Natural Resources

A balanced system of natural resources is one that is self-perpetuating, even while being used sustainably by humans and animals (Dahlman & Renwick 2015). Balanced systems represent the most efficient use of natural resources that do not negatively impact the environment (Lindenmayer & CSIRO 2007).

> It is harder to reconstruct ecosystems than to destroy them. This is one of the very important reasons why it is absolutely essential to keep our ecosystems functioning (Lindenmayer & CSIRO 2007, p.22).

The following two examples show how changes in one natural resource causes flow on damning effects to other natural resource factors.

The program to eradicate cats on Macquarie Island, a world heritage site approximately 1500km south East of Tasmania is a perfect example of good intentions causing devastating effects (Bergstrom et al. 2009). The introduced species of cats, rabbits, rats and mice, were destroying the native ecosystem. Initial eradication programs were put into place to reduce the rabbit populations, unfortunately the reduction in the rabbit population caused the increasing cat population to have a detrimental effect on the island seabirds. Subsequently, a $6 million intensive cat eradication program was implemented from 1985, with the last cat being destroyed in 2000 (Department of Sustainability & Division 2011). With their main predator destroyed, the rabbit, rat and mouse populations exploded causing devastating impacts upon both the flora and fauna of the island (Bryant & Shaw 2007; Bergstrom et al. 2009). Envisioned as an ultimate solution, an ongoing pest eradication program was introduced in 2009 at a cost of $24 million. As at June 2012 the island is once again approaching a primarily native ecosystem (DPIPWE 2012). The significant cost of the solution could have been considerably reduced if the original cat eradication program had been balanced to include simultaneous reduction of other pest species.

The importation of Cane Toads into Australia is another classic example demonstrating disastrous economic impacts caused by a lack of comprehension of the interaction between natural resources. The cane toad (*Bufo marinus)* was introduced into Australia in 1935 to control sugar cane beetle pests in Queensland. The cane toads did not control the cane beetles, instead they devoured the native prey species (Lindenmayer & CSIRO 2007). Cane toads are highly toxic, so they have no natural predators in Australia and rapidly reproduce (Goodgame 2004). Cane toads are currently found in Queensland, Northern Territory and New South Wales meanwhile they are expanding their range by 50km per day. Cane toads were imported without empirical evidence to substantiate their effectiveness against already existing sugar cane pests (Goodgame 2004). The decision to import cane toads has a continuing detrimental effect on the native species of Australia.

The importation of cane toads and the cat eradication program on Macquarie Island demonstrate consequences arising from decision making that has not adequately considered the impact upon the natural resource base.

2.2.4 Current Methods of Education and Information Dissemination to the General Public

The point of disseminating information about natural resource issues is because an understanding increases the chance that natural resources will be considered during planning and decision-making.

Typically natural resource associations, including Municipal, Government organisations and Non-government Organisations (NGO's), promote their issues through the media, social media and via networking through established natural resource connections (NRM North, pers. comm., 16 Feb). The issue content is typically delivered in the form of factsheets, webpages, planned field days, scheduled group training sessions, or as packaged education programs for school curriculums (M Black 2012, pers. comm., 16 Feb). Occasional special days such as open days, agricultural shows and local festivals provide an opportunity to speak personally to local experts while viewing booths filled with pamphlets, posters and hands on displays. Naturally, these displays work well when they appeal and engage a wide audience, so a blanket approach is adopted using a variety of styles in order to appeal to a wide audience.

2.3 Comprehension and Understanding

This section defines what is meant by understanding, then investigates how adults learn, why they learn, and what appeals to them to learn.

2.3.1 What is Comprehension?

Comprehension is a direct result of learning (Brett et al. 2014). It is one level of understanding along a depth of knowledge scale, starting with reiteration of facts and finishing with an expert understanding (Anderson et al. 2001). Numerous taxonomies have been developed to describe, categorise and measure education goals. Bloom's Revised Taxonomy is a well-recognised accepted style that defines the cognitive acquisition and implementation of knowledge in six stages (Anderson et al. 2001). The stages are: Remembering, Understanding, Applying, Analysing, Evaluating, Creating (Anderson et al. 2001). Each stage demonstrates an increasingly deeper understanding of the knowledge domain, as shown in Figure 2. Other taxonomies such as Structure of the Observed Learning Outcome (SOLO) (Biggs 1979) and Fink's Taxonomy (Fink 2003a) exist, but Bloom's Revised Taxonomy clearly defines differences between levels of understanding and better suits our purpose. Therefore Bloom's Revised Taxonomy will be used as a guide to develop a range of tasks across these stages in the experiment stages of the project.

The aim of this research is to improve understanding of natural resources so that natural resources are considered as part of decision making processes.

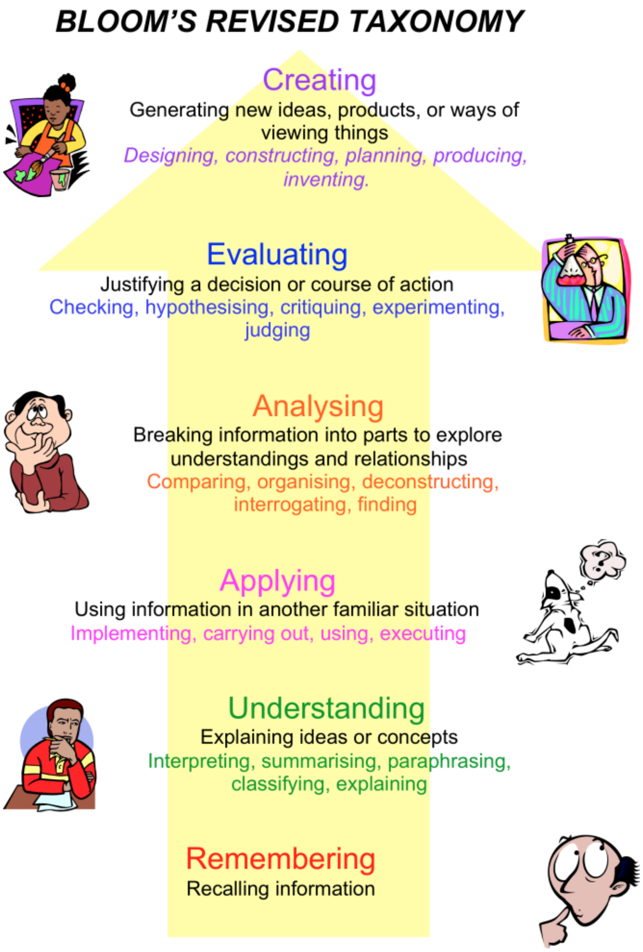


Figure 2: Blooms Revised Taxonomy(Queensland/Education 2010)

Comprehension should be considered as is an equivalent term to understanding and entails the following: to perceive the meaning, or to grasp the significance of implications and be able to understand clearly the character, nature, or subtleties of the subject. It is expected that comprehension will be achieved by the process defined by Oliver of 'simultaneously extracting and constructing meaning through interaction' (Oliver 2009, p. 403). The interactions ultimately are responsible for the construction of knowledge (Oliver 2009). Interaction is a fundamental building block for learning with computer based systems.

2.3.2 Personalized Learning

This section addresses how adults learn.

A popular current theory in education is personalised learning (Robinson 2010). Generally teachers are no longer encouraged to spend time attempting to identify the individual learning styles of each student, hence material is presented in a style suited to most of the class. Instead the teaching materials are provided in a blend of learning styles where the content is presented and available in a variety of forms, so that each student may choose what works best for them (Blondy 2007). This is called personalised learning (Blondy 2007). Personalised learning aims to maximise the flexibility of the medium of learning, by allowing the student to use the optimum mix of teaching mediums and materials (e.g.. paper, clay, electronic devices) that they believe work best to assist their learning (Robinson 2010). The goal is learning by any means, where one preferred learning style is not considered better than any other.

Material is presented in several styles reinforcing the content, along with extensive practical exercises to apply the theory. A variety of teaching resources are available in today's classrooms. These include smart boards, eboards, personal netbooks, internet, multi-media and e-learning, which are all readily available to support the traditional books, whiteboard and handouts. Personalised learning is actively applied in the private schools in Tasmania, Australia.

2.3.3 Learning Styles

The Visual/Audio/Kinesthetic (VAK) model (Lujan & DiCarlo 2006a) is a well-known and commonly understood style. In the VAK model: Visual learners learn best from observation, Audio learners learn best from listening and Kinesthetic learners learn best by doing (Foster 2008). Fleming (1995) expanded the VAK style to VARK, to include a category to accommodate those who prefer to learn from reading and writing (R). Many people associate themselves with one of these learning VAK styles and show a preference to a particular method for learning new tasks, although most of us actually learn better with a unique combination of these three styles with a preference to one or two in particular (Lujan & DiCarlo 2006; Fleming 1995). Fleming (1995) devised a questionnaire that categorises a learner into their preferred learning style.

Learning styles are an attempt to define categories for the manner in which people learn. Whereas VARK shows how people learn, learning theories show ways to teach.

There are many learning theories: cognativist, behaviorist, humanist and constructivist (Ormrod 2004). The most relevant to this thesis is Constructivism (Foster 2008). It is a learner focused theory rather than subject focused, meaning that the actual manner that learning occurs is determined by the learner (Foster 2008). The learning is shaped by each individual learner's experiences, conceptions and mental model of the world. Every student has their own mental models that conceptualise their understanding of their experiences incorporating everything they know and understand (Ormrod 2004).

Piaget, perhaps the most well-known constructivist, believed that learning is achieved through assimilation and accommodation (Piaget 1962). When new knowledge is encountered, it is compared to existing mental models. If it matches then the new information is assimilated into that model. The new information is well understood because the learner already knows all the rules, form and criteria in their existing mental model and these now apply to the newly acquired information. When new knowledge does not match existing mental models, then a new mental model must be defined to accommodate this type of information. The mental model creation process takes time and a deep level of thought. The new model is categorised into the existing collection of mental models. Assimilation is much simpler to accomplish than accommodation, thus it is easier and quicker, to (either deliberately or sub-consciously) misinterpret the characteristics of new information so that it fits existing understanding (Foster 2008).

Vygotsky, another proponent of constructivism, proposes that social and cultural paradigms provide significant contributions to learning and knowledge retention (Duncan 1995). Vygotsky considers that the social interaction of collaboration and cooperation, as conversation or written dialogue is essential to develop understanding. A by-product of collaborative communication is that it raises the understanding of the viewpoint of others, thus reducing miscommunication problems. Vygotshy's paradigm for the contribution of social interaction is not a replacement for Piaget's theories, rather it explains one method of how knowledge may be better understood while it is being learnt.

Constructivism is based upon the theory that knowledge is learnt by being constructed in some form as part of the learning process (Piaget 1962). The construction may be purely mental, but is more likely to be caused from physical interaction (practical application) and/or collaboration with others with a similar goal (Duncan 1995). In a digital learning environment, Rick et al., (2009, p. 323) state that 'A core challenge for constructivist educators is designing environments that enable learning by doing, where learners actively engage with a domain through exploration and creation.' In a virtual world example this is resolved by providing navigation and enquiry tools, so the learner may move in their own direction, at their own pace.

Much learning theory is focused upon children, rather than adults (Ormrod 2004). Andragogy is the study of adult learning. Andragogy was developed into a theory that outlines the following six core principles (Knowles et al., 2005):

1. Need to Know – Adults like to know why they need to know something,
2. Learner Self-concept – Adults have an understanding of what they want to learn for themselves and direct their learning appropriately,
3. Learner's Experience – An adult's experience contains their mental models of how the world works,
4. Readiness to Learn – Adults prefer to learn about topics relevant to their current work or life interests,
5. Orientation to Learning – As people age, they prefer to learn to better their current situation, or current problems,
6. Motivation to Learn – Adults have their own internal drives and reasons to learn (Curiosity, self-accomplishment).

Blondy, (2007) notes that the Knowles et al. (2005) core principles of andragogy have foundations in constructivism. The core principles show that practical application of new knowledge in suitable context using real world objects (the kinaesthetic learning style) is an effective learning mechanism for adults Blondy, (2007).

The role of the kinaesthetic learning style is singled out in Section 2.3.4 below because it is an overlooked minority with strong learning capabilities (Gage 1995, Ross et al, 1998).

2.3.4 The Role of Kinesthetics in Learning

Education techniques often "favors those with auditory or visual modalities, while virtually ignoring those with kinesthetic strengths" (Gage 1995, p.32). This leads Ross et al. (1998, p.56) to ask "How can we incorporate more kinesthetic teaching strategies in a simple way?"

Extensive research by Piaget (Price et al., 2003) shows that young children gain significant learning advantages by using objects (kinesthetic) as part of the teaching process (O'Malley & Stanton Fraser 2004). Using physical objects allows children to look at the problem from different viewpoints; to experience and explore the situation with the objects. Handling physical objects helps to build memory cues reinforced by the touch, texture, shape and use of the object which aid in recall (Mcgookin et al. 2010).

In his study on The Role of Kinesthetics in Learning Etemad (1994, p. 19) states 'The literature shows that learning activities that involve some tactile experience increase the development of positive attitudes towards the content being learned.' (Etemad, 1994, p. 19). Therefore practical hands-on interactions with objects are a positive endeavour as objects jointly stimulate the senses and mind of the student and increase their attention focus. Etemad (1994) claims that students who are actively involved in learning by engagement with physical materials have a better grasp of information, than those who learn through only visual or auditory methods. This is supported by Piaget's theory that children need to practically undertake a context specific activity in order to learn (Clements 2000).

Empirical studies with children shows physical props aid in learning by reflection, as they allow the student to use the prop to experience the information in different ways (Price et al., 2003). O'Malley & Stanton Fraser (2004, p. 37) claim that children can solve problems using physical materials when they are unable to solve them in their head. Furthermore, this same problem will be easier to solve next time without the aid of physical materials, simply because they now have successful experience with this type of problem.

Prominent learning styles (Section 2.3.3) establish that kinesthetic learning has essential mechanisms for developing a thorough understanding of new concepts. Furthermore, empirical evidence proves that interaction with physical objects enhances attitude, focus, memory, aptitude and problem solving (Price, Rogers, Scaife, D Stanton, et al. 2003; Etemad 1994; Mcgookin et al. 2010).

2.4 Interface Types for Natural Resources and Learning

This section discusses the limitations to the current methods then justifies the argument for emerging technology types.

Although current natural resource information (Section 2.2.3) are well designed, each factsheet, pamphlet, poster, news item, or website is primarily in written form. Written form works well when it is read in its entirety. Unfortunately, we live in a busy world with continuous competition for our time, so we tend to skim written documents, potentially missing key points and caveats. Consequently, the existing systems are only partially successful and do not guarantee that the information presented is even read, let alone understood. However, an informative computer based system with interactive feedback could counter this problem. The system would need to be flexible for the user, while being inviting and engaging to the broadest range of people within the potential target audience. Such a system would control the flow of information ensuring that the key points and caveats are presented and do so in a manner that maximizes the likelihood of them being understood. Lastly, the system could reinforce the user's level of understanding through application of concise training scenarios.

New mainstream Human Computer Interaction (HCI) technology may offer advantages over traditional systems. Emerging technology may provide engaging new techniques capable of demonstrating the complexity of natural resource interactions in a manner that ensures they are engaging, memorable and well understood. For the purposes of this research emerging technology is defined as technology that is becoming available in the mainstream, which includes touch, multi-touch, augmented reality, tangible systems and hybrid systems.

This section will review the new interface styles available, show how they have been used for natural resources applications (preferably for educational value), evaluate the pros and cons, then review comparison studies to select the most appropriate interface type for the purpose of developing understanding of the dynamics of natural resources. This technology will be evaluated against existing Graphical User Interfaces (GUI) and Web 2.0, to attempt to identify the features that may provide advantages not presently available.

2.4.1 Virtual Reality (VR)

Virtual Reality (VR) refers to computer simulations where the user is so immersed within a virtual computer simulated environment that they only see, hear, experience and interact with the virtual world (Milgram & Kishino 1994). The virtual environment can be displayed within a head mounted display, with sound routed to earphones within the display and the movement of the head controls the view within the VR. Alternatively, Cave systems such as VRFIRE (Figure 3), display the virtual environment on the walls, floor and ceiling of a room (Sherman et al., 2007). The user movements are tracked and the display is updated accordingly. A significant component of VR is the ability to interact with the virtual environment. The lowest level of interaction is merely to navigate within the virtual space. The highest level of interaction permits the user to interact with the surroundings as they would in the real world, so that they can move and manipulate elements within the virtual world in a logical, meaningful manner.

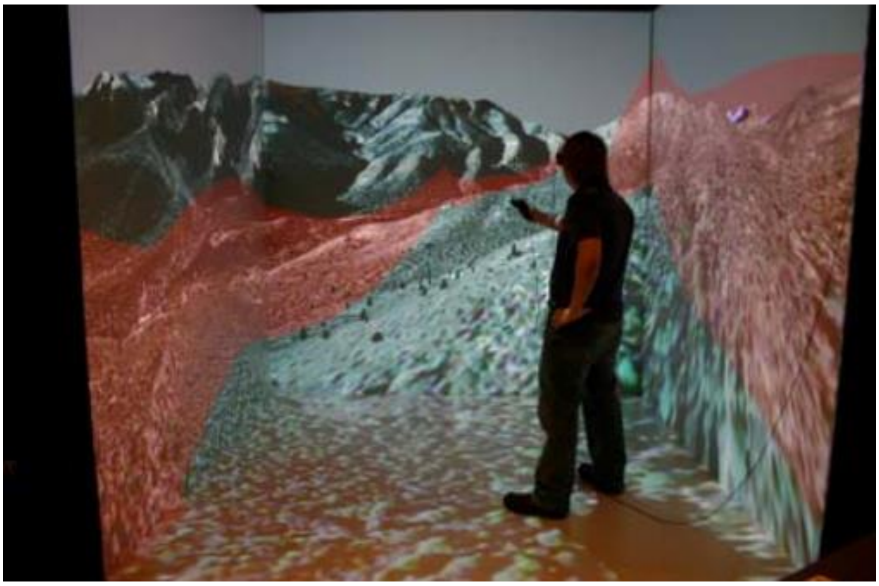


Figure 3 VRFIRE - at the fire boundary (shown in red) (Sherman et al., 2007).

VR enables interaction within a virtual environment that may not otherwise be possible in the real world. Examples include simulations of surgery on the human body, walking through proposed building architecture plans, being on another planet, simulating a disaster and training simulations where mistakes would cause physical harm (Furness 2012).

In actuality, VR is implemented with varying degrees of immersiveness. Advances in computer graphics chipsets, combined with advances in game development and design, have significantly improved the realism of virtual reality by improving sound and visual quality. However, simulation requires that the experience both looks and behaves realistically. Simulating behavior can be difficult, because behavior may be too complex to model, or because the behavior is not fully understood, or because there may be insufficient information to simulate the appropriate behavior. In this case the VR experience is limited.

An alternate style of virtual reality is created within desktop virtual worlds. Game engines can add appropriate behavior to objects when they are included in a virtual world. Unity (a development game engine) will show the effects of wind on grasses and automatically move grass aside when other world objects pass through. The game engine will also control gravity and collision detection. These virtual worlds look and behave realistically and these are commonly referred to as a virtual reality, even though they are only displayed on a computer monitor. The display on the computer monitor may be highly engaging but it only shows a window-on-the-world and is not fully immersive (Milgram & Kishino 1994). Game engines will apply ever more natural world behavior as these are more clearly defined or simulating methods become available.

2.4.2 Augmented Reality

Augmented Reality(AR) is a computer vision technique that overlays virtual content in the real world (Billinghurst et al., 2009). A well-known example is the first down line shown in broadcasts of American Football (van Krevelen & Poelman 2010). The live feed is delayed while a virtual yellow first down line and distance information is added to the video feed (Figure 4). This digital information augments the reality of the game and significantly adds value to the experience.

AR as originally defined by Azuma (1997) as ‘systems that have the following three characteristics:

1. Combines real and virtual
2. Interactive in real time
3. Registered in 3-D’

Figure 4: First down line in Gridiron(HowStuffWorks 2012)

A well-known early AR application is *The Magic Book* (Billinghurst & Kato, 2001), an interactive story book, where each page shows animated 3d models representing the story, culminating with the final page which allows the reader to enter the story to become an interactive character in the virtual story world. The reader may move and interact within the virtual world and see the real world in context from within the world. The Magic Book meets the three criteria of Azuma's definition of AR.

AR traditionally uses uniquely identifiable images (AR makers) as a guide for the virtual content. These AR markers exist in a printed form and placed into view of a camera by the operator (Billinghurst & Kato, 2001). AR software locates the unique AR markers in the video images and replaces the marker image in the video stream with virtual content associated with the marker, typically a 3d model. The augmented image is viewed via a standard computer display screen, or via a head mounted display, or it may be projected on to a surface. If a head mounted display is used, then the orientation of the head can be tracked to provide feedback to the AR system, so that the view is centred for the operator's perspective (Azuma 1997). One person can only use a head mounted display at a time, while multiple people can view a display screen simultaneously.

Sea Lab (Redondo Beach, California) (Mendham 2010) use an augmented reality information kiosk to educate visitors on the long term effects of pollutants on the local shoreline species (Figure 5). The visitor selects one of three information cards, then holds it in front of the camera to start the activity. The activity shows an animated 3d model of the creature and its habitat. The model is accompanied by an audio track and pop up information balloons that explain the continuing effects on the environment cause by the pollutants and their ongoing impacts upon the selected species.

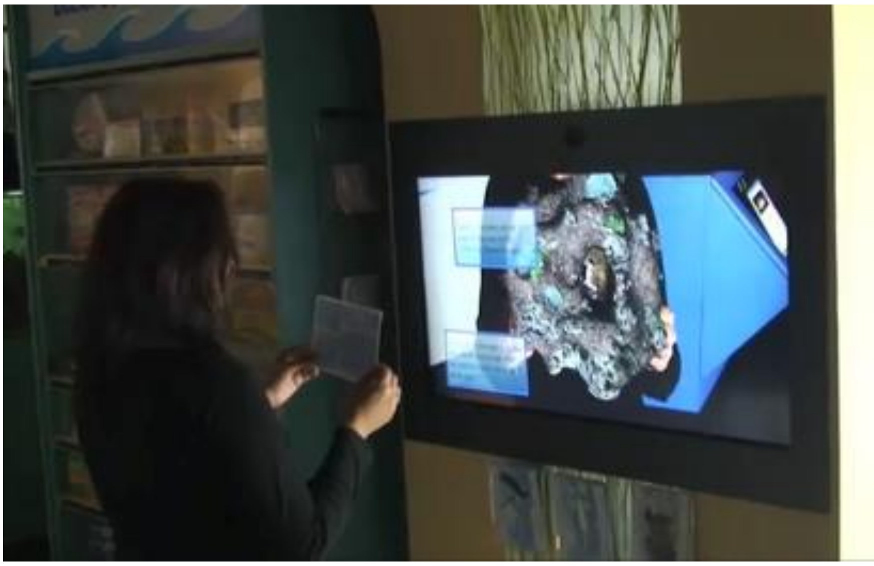


Figure 5 SEA LAB Augmented Reality Eco-education for Pollutants

AR has substantial applications and market penetration in the mobile arena. Initially mobile AR was restricted to Personal Data Assistants (PDA) and Tablet PC's (Wagner et al., 2010), however, smart phones and tablets provide an ideal platform for AR. New release phones and tablets have increasingly more powerful processors, cameras and displays. This technological capacity combined with the mobile AR development environments makes creating AR solutions for mobile devices a viable growth industry (Gentile et al. 2011).

2.4.3 Multi-Touch (MT)

A Multi-Touch system is centred around a display that is controlled by touch from two or more concurrent touch points (Rick et al., 2009) (A touch point is a location on the screen that is activated by a stylus, finger, or object.). Multi-touch allows the user to interact with and manipulate digital data with touch interactions in a natural intuitive manner, usually with finger gestures (Kaltenbrunner et al., 2005). This direct manipulation of graphic representation of the data, according to Shen, Everitt, & Ryall, (2003) is a more appealing and natural means of input.

Primarily, multi-touch systems are large format displays in either vertical or horizontal position. The vertical systems are often for information displays, or collaborative white-board style workspaces. The horizontal displays (tabletops) are used for collaborative graphical environments (Fleck et al., 2009). Multi-touch systems provide dynamic content, with a flexible, dynamic interface (Tuddenham & Kirk 2010). The content and interface elements can be created, copied, deleted, resized, reorientated and reconfigured in a variety of formats and styles, which allow a very high degree of customisation to suit the users' needs. (Shen 2004, p. 167) notes, 'tabletop user interfaces should preserve many of the familiar and useful properties a physical tabletop affords and allow the natural interaction that people usually carry out on physical tables'. These interactions include moving papers between people using the table, or grouping and stacking documents. Tabletop multi-touch systems are a proven collaborative problem solving and decision making environment that is more likely to stimulate 'contributions from all members of a group'(Rick et al., 2009, p. 323).

Figure 6 User Interface Design of Futura - Sustainability Futures Game (Antle et al., 2011a)

The collaborative multi-touch game, Futura, was developed to raise the awareness of sustainability issues as the world population increases (Antle et al., 2011). Futura was specifically designed for simultaneous collaborative use, by the general public, in a publically available site. It requires two – six players to work collaboratively to achieve the goal. Each player must win for the group to win, thereby encouraging collaboration between players. In the game (Figure 6), the population is increased in real time (not on a turn based system) and the players must allocate facilities, such as farms, power stations and housing, to sustain the population. Each facility has a specific negative impact upon the environment. The game is won when the population is happy and the impact on the environment is low. The players are shown a summary of statistics and achievements, at the end of the game. Futura is designed to be replayed to hone sustainable planning skills. 90 people played Futura in a public venue at the 2010 Winter Olympics. Some players did not understand how the environmental effects related to their actions, because they were unable to establish if they, or other group members, caused the problem. Overall the project was deemed a success as the majority of the players found it engaging, fun and educational.

Touch has been accepted as a mainstream use of technology. Touch information kiosks are commonplace so that it is not unusual to see people actively touch flat screen monitors in public areas expecting them to be an interactive touch kiosk. Recently, the smart phone with its multi-touch gestures has significantly raised the awareness of multi-touch amongst the general public (Hodges, et al., 2007). Smart phone users can apply their experience from their phones to multi-touch systems because touch gestures typically perform standard functions between applications and platforms, i.e. double tap to activate and two finger pinch to zoom. Tablets provide a larger work surface (7-10 inches) than a smart phone, yet include the same functionality. The introduction of the hand held tablet has taken users another step closer towards familiarity with large format multi-touch systems.

Although multi-touch systems have been available for a couple of decades (Hilliges et al., 2010) they have had little market penetration, till recently. The change is caused by the combined effect of smart phone, tablet and lower entry level prices for large multi-touch surfaces (Hilliges et al., 2010). The highly publicised and long awaited, commercial release of the Microsoft Surface 2 presently spearheads the market penetration. The Surface was released at a cheaper price than any of its competitors (ReacTable, DiamondTouch) and in much higher volume. The release of the Microsoft Surface is a significant step towards large format multi-touch becoming mainstream technology. Subsequent to the release of the Surface, a flood of companies have released multi-touch surfaces (Ideum's MT65 Presenter, HP VantagePoint) (Interfaces 2012; Engadget 2012).

The smart phones and tablets have trained a pool of people who are familiar, satisfied and competent users of multi-touch. This user pool will easily migrate their skills to using a large format multi-touch system. Now large multi-touch systems are readily available. The world is ready for multi-touch to be a useful, productive mainstream technology.

2.4.4 Tangible User Interface (TUI)

A Tangible User Interface is a system that allows users to physically interact with 'data by coupling it with every day physical objects' (Ulmer & Ishii 1997). Physical objects are used to represent, or display, digital information, or they are used to interact with digital information. Tangible user interfaces appeal to a range of people because they allow users to physically touch and manipulate controls with their hands, just like everyday objects (Shaer & Hornecker 2010; Ishii 2008). Preece et al. (2011) state that TUI provide the opportunity for dynamic information to be presented in alternate ways, offering the potential to for increased intuitive understanding, problem solving and learning over traditional user interfaces.

Tangible User Interfaces offer the following benefits:

- externalise internal representations,
- enable use of purpose designed, context sensitive input devices,
- allow creation of interface elements that are immediately accessible and manipulable,
- make use of knowledge of everyday objects as interface elements,
- 'Users receive passive haptic feedback from the physical objects as they grasp and manipulate them.' (Ishii, 2008, p. 7),
- ease of use, as the affordances of physical objects are inherently richer than virtual counterparts,
- pairing of tangible objects with digital feedback,
- enable effective use of spatial reasoning skills and
- allow for parallel input by the user.

TUI are designed in a very wide range of forms and applications (Section 2.5.4). The following example outlines only one of the many styles of TUI. Researchers at North Carolina State University have extended the MIT Media Lab Illuminating Clay project (Figure 7), by linking the clay landscape to a Geographic Information Systems (GIS). The researchers call this system Tangible Geospatial Modelling (TanGeoMS). The research project team have an appreciation for the potential of Illuminating Clay to natural resources, as demonstrated by their strong bias towards sustainable land management applications (Piper et al. 2002). The GIS is used to process analytical environmental models then display the results over the clay landform. The scanner can track real-time changes to the clay landscape, feeding this information to the GIS, to change the information projected on the clay landform.

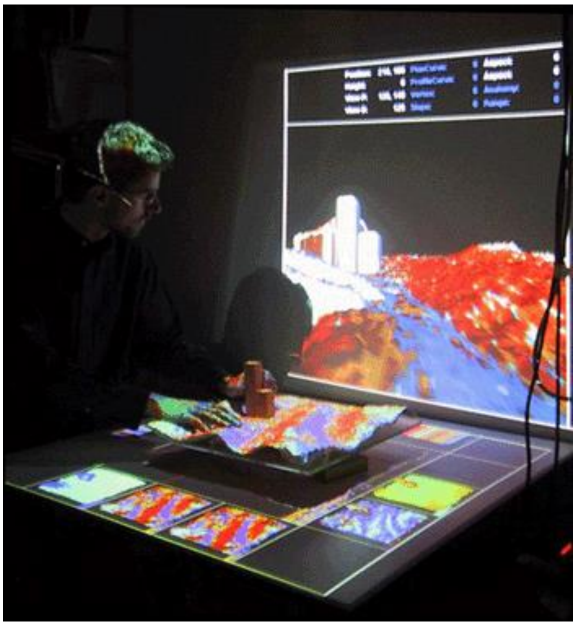


Figure 7: Illuminating Clay showing landform analysis (Piper et al., 2002).

This system shows real-time interaction in a 3d physical landscape (Mitasova et al. 2006). Physical objects (i.e.. scale model dams) may be added to the model, where the GIS will analysis their impact using a simulation model. The GIS results are displayed as a projected overlay on the clay landform, as well as in numerous windows supporting map forms surrounding the landform model. TanGeoMS was used to evaluate a variety of erosion control measures. Simulations were created for each erosion prevention proposal and the results were projected as a time series animation on the clay landscape. This process clearly showed the impact of each erosion measure. Subsequent tests enabled combination of erosion measures to be evaluated, till the most appropriate combination was identified. Further studies investigated coastal protection, impacts of new developments and assessment of site location for solar energy installations.

The TanGeoMS 3d clay landscape concept is suitable for group work and is capable of displaying multiple types of data, from supporting maps to statistical information. In addition the system permits spatial information to be projected over the 3d clay landscape. However, it has limited context because the bounding box containing the clay landscape is a relatively small size and can only be modelled at one mapping scale at a time. Any project that uses TanGeoMS must decide on the trade off between the level of detail that is useful and the size of the area to be modelled.

Further examples of TUI applications using Natural Resource are outlined in Section 2.7.

2.4.5 Comparative Evaluation

It is clear from the examples above (Sections 2.4.1 - 2.4.4) that each of these interface types are suitable for systems for improving understanding of natural resources. The following sections will evaluate the pros and cons of the interface types by review of research that compares interface types. This review will identify the most suitable form of interactive interface for a system to instil an understanding of the dynamics of natural resources for the general public.

'People have developed sophisticated skills for sensing and manipulating our physical environments. However, most of these skills are not employed by traditional GUI (Graphical User Interface)' ('Tangible Media | MIT Media Lab,' 2012). The MIT Media Lab specialise in developing applications for human computer interaction using new technology.

Augmented Reality is a very versatile application platform, however it is limiting as it is mainly used by a single user, with further inherent restrictions on interactions because of occlusion problems cause by hands, or by orientation of the AR Marker (or tracked symbol) to the camera. However, projected AR, where the display is projected over a surface as in the Illuminating Clay (Piper et al., 2002) example, offers the most potential AR for our purposes, as it is collaborative, engaging and interactive, with minimal occlusion issues. Furthermore, projected AR may use touch and multi-touch as the interface. Finally, this style of AR can be enhanced by using tangible objects into a Tangible Augmented Reality system, as observed in the TanGeoMS system (Section 2.4.4).

A study by Xie & Antle (2008) comparing a virtual jigsaw, operated by a traditional mouse (VR) and menu system and a virtual jigsaw controlled by tangible jigsaw pieces (TUI) (Figure 8), observed that children found the TUI to be more engaging and playful than using the mouse (VR). The research clearly showed that children preferred the tangible jigsaw (TUI) to a virtual jigsaw (VR). The children noted that they were unfamiliar with the controls for the virtual jigsaw, whereas they could easily understand and use the controls for the tangible jigsaw puzzle because they were physical jigsaw pieces and they behaved exactly the same as any standard jigsaw. The children also liked that they could work collaboratively using the tangible jigsaw, however they were only able to use one piece at a time with the virtual jigsaw. Xie & Antle claim that the problem with the virtual jigsaw was a combination of 'single user access and the difficulties imposed by using an indirect interaction mode constrained to a 2D space' (Xie & Antle 2008, p. 197).

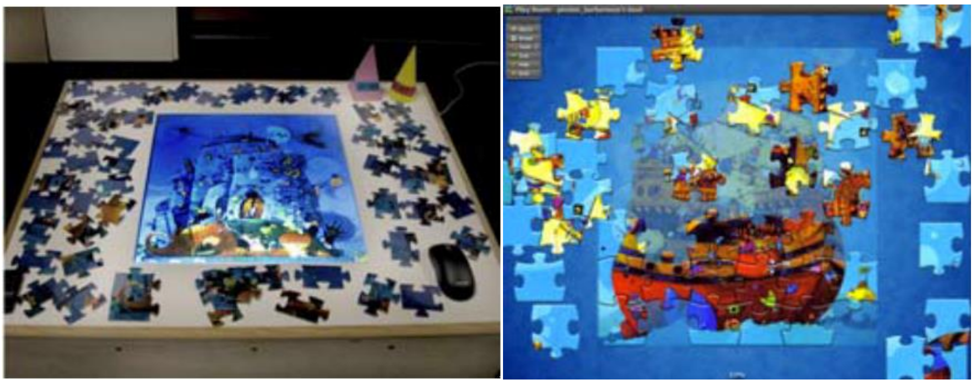


Figure 8: Tangible and virtual jigsaw puzzle (Xie & Antle, 2008).

Similar preferences were found for adults when using the geology tangible user interface, GeoTUI. Geophysists clearly determined that tangible interactions performed quicker and more effectively than using a mouse and keyboard (Couture et al., 2008). The Geophysists benefited from the tactile response and direct control available by using their hands in a tangible user interface.

A comparison study by (Triona & Klahr, 2003) of training, using virtual and physical materials, found there was no significant difference of physical objects over virtual. In their example the results are qualified by the acknowledgement that 'the physical interaction with the materials was unnecessary in this learning context, therefore the lack of preference may well reflect indifference on behalf of the user (Triona & Klahr, 2003). Triona and Klahr believed that the users thought the use of physical objects was gratuitous rather than a required need. This outcome implies that tangible interface designs should avoid gratuitous use of physical interface objects as they offer no benefit, and may have a detrimental effect.

A recent study on primary children, evaluating a tangible programming system called Tern to an equivalent graphical mouse driven interface, found that Tern 'offered advantages for learning' in two of the three scenario studies (Scharf, Winkler, & Herczeg, 2008). The qualitative observation results showed that the tangible interface seemed highly suited for collaboration with group activities and discussions, in both museums and the classroom. Furthermore, in the museum, more children (an equal number of boys and girls) attempted the programming with the tangible system than with the computer based graphical system. In addition, the observations showed that the children switched between using the GUI and then TUI, with very few only using one system. The recommendation of the research was that a hybrid tangible/graphical interface may be the best solution for the Tern study scenarios.

Following on from this recommendation, a hybrid prototype was developed and evaluated in a live situation, where it was observed that the children preferred the tangible interface for building the initial system. However, they preferred the graphical interface for correcting and redesigning the system. Interestingly, the tangible system attracted an equal number of boys and girls, whereas the GUI was dominated by boys.

Early empirical studies comparing multi-touch surface and tangible multi-touch surface found no discernable difference between the two (HP 2012). Terrenghi et al argued that tangible multi-touch systems could be replaced by multi-touch systems, as the tangible object can be replaced by a virtual object assigned the same functionally as that of the object. This argument is a functional perspective only, it does not take into account the level of engagement, ease of use, or user preference. Use of virtual objects eliminates haptic feedback and the physical third dimension beyond the screen is made obvious by tangible objects. Although, gesture and touch have some degree of haptic interaction, it is at the lowest possible level, as it only affects the finger tips when using the flat surface. People like to work with their hands, so removing the tangible objects reduces the potential engagement of the interface.

Recent experiments show tangible surface touch systems to be quicker and more accurate to use than multi-touch surface gesture controlled systems (Lucchi et al., 2010). Lucchi et al's study required 40 students to duplicate the shelf layout of a set of warehouses, using both a multi-touch surface and a tangible multi-touch surface. The shelf units are a modular design meaning that all the different shelf configurations were made from combining units of one size of shelf. In the multi-touch system the shelf units were represented as a rectangular graphic, which is positioned by touch and orientated by gesture. In the tangible system the shelf unit is represented by a physical tangible object made to scale. The experiment measured the speed and accuracy to build shelf units to match a series of different warehouse layouts. The results showed that the participants felt more stressed using the touch interface and that they believed they were more successful with the tangible system, even when the results showed they performed equally well in the touch system. The completion times using the touch system varied significantly, while the completion times using the tangible touch surface were consistent as well as being faster and more accurate.

The research by Lucchi et al., (2010) is one of the few examples that targets adults. Many of the experiments for learning with TUI are specifically designed for children. One reason that contributes to the success of the research by Lucchi et al., (2010) is that it targets a clearly defined problem, a niche topic - a strategy recommended by Ishii (1997). Lucchi et al's research is validated by comparable research with results showing TUI to be more efficient than touch systems (Schneider et al. 2010; Triona & Klahr 2003).

The niche topic of the (Schneider et al. 2010) research is specialised training. Furthermore this project has substantial commercial potential because specialised training courses have a strong, captive market thanks to certification requirements for Occupational Health and Safety (OH&S) as well as training requirements for in-house performance management. Schneider et al's (2010) example of the warehouse design training system is a positive example in a very lucrative market. Perhaps specialist training should be a focus for TUI, if they are economically feasible. Future research studies could define the characteristics of training that would be suitable for TUI. Not all training would suit a TUI, possibly because:

1. The development costs for either UI or hardware exceed the benefits, or
2. The problem space does not translate into a tangible user interface, for example, tax law changes may not translate into a useful TUI.

Tangible multi-touch surfaces are easier to learn and more accurate to use than a mouse driven GUI, or a multi-touch surface (Tuddenham & Kirk, 2010). Tuddenham & Kirk conclude tangibles to be better than other inputs which validates the seminal experiments by both Buxton and Fitzmaurice (Fitzmaurice, Ishii, & Buxton, 1995).

2.4.6 Interface Types Suitable for all Learning Styles

This section matches emerging technology with learning styles in order to identify which appeals to the largest potential audience.

All mainstream interfaces use audio, written and visual cues, to convey purpose and function to the user. This is works well for visual, audio and reading type learners, but is not necessarily an advantage for the kinesthetic learners. In theory an interface with haptic or tactile controls would potentially be most useful for kinesthetic learners.

Traditional graphical user interfaces (GUI) and touch interfaces, are not able to use physical objects and therefore lack this extra dimensional aid for learning. Similarly, Virtual Reality (VR) lacks the interaction from tangible objects, even though responsive custom designed controllers may control them, they provide a dominant visual experience rather than a kinesthetic one. Finally, although Augmented Reality (AR) does use tangible objects, the way these objects are used does not provide the rich haptic experience of tangible user interfaces (TUI).

TUI is a flexible design form, which is why many taxonomies have been developed in an attempt to categorise them. Of these, multi-touch surface tangible user interfaces have versatile key features that allow digital content, in all of its forms (textual, image, video, animation, web, audio, spatial information) to be directly linked to tangible objects and then be controlled by a choice of touch, gesture, or tangible object. The digital to physical object link value-adds to the educational benefits of kinesthetics, because the digital (virtual) component provides both visual and auditory learning benefits in addition to the benefits of learning by kinesthetics. This ensures that multi-touch surface tangible user interfaces have the potential to be easily understood by all VARK learning styles.

2.4.7 Interface Suitability to Current Learning Methods

The evidence presented in Section 2.4.6 suggests that multi-touch tangible systems offer the greatest benefit over other types of Interfaces for learning, as they are empirically proven to be preferred for learning because of their level of engagement, flexibility, ease of use and efficiency. Multi-touch tangible systems have all the advantages of computer based learning contexts (GUI, internet, e-learning, multi-touch) combined with the tangible elements for input and output of information, therefore should easily integrate into the personalised learning system.

2.4.8 Interface Suitability to Dynamics of Natural Resource

A comparison of examples of tangible GIS systems with natural resource applications will show which style of tangible user interface is most suitable for this purpose. The

MapTable is used by the Dutch ministry for transport, public works and water management to evaluate the impact of changes to town planning boundaries. The changes are drawn on a tabletop using a stylus directly onto a map which is augmented by projecting other maps and results over the map. This is similar in basic design as the TangiTable used by the model and design business RoVorm, to perform pre-set GIS actions displaying results projected directly onto a table. The pre-set actions are controlled by placement of tangible objects. Both the MapTable and the TangiTable systems (described in detail in Section 2.7) have the capability to display some natural resource information at any scale, for any region of interest, however these systems will not display the full range of natural resource information types and have limited functionality (Scotta et al. 2006). The Tangible GIS solution, TanGeoMS, has functionality to view all the types of natural resource information, however it is severely restricted by the physical limit of the clay box. A hybrid system combining the data display and analysis functions of TanGeoMS with the display capacity of the MapTable will use the most useful features of these systems and have the potential capacity to simulate the dynamics of natural resources. This style of TUI is a multi-touch tangible system.

2.4.9 Preferred System

The evidence presented in the previous sections clearly shows that potentially the most successful, versatile and engaging system for natural resources and learning for adults and children is a hybrid system that has the following factors:

1. intuitive interactive interface with appealing visual feedback,
2. horizontal large format display,
3. tangible objects and
4. multiple simultaneous touch.

A hybrid system using tangible objects on a horizontal surface, which uses a visual multi-touch system has been indicated as potentially the most beneficially interface configuration for improving the comprehension of the dynamic of natural resources. The described system incorporates all the potential benefits of touch, multi-touch, gesture, natural user interaction, collaboration, group interaction and single user operation. Such a system is a multi-touch tangible interface in a horizontal orientation.

2.5 Tangible User Interfaces

Now that TUI have been chosen as the preferred emerging technology, this section will review pertinent aspects of TUI.

2.5.1 Tangible Object Nomenclature

A Tangible object is a physical object that is used to interact with the computer system. Tangible objects are known by several names that are interchangeable: Token, physical object, artefact, tangible object, Pyfo (Shaer et al., 2004), representation and manipulatives. In this thesis tangible objects will be referred to as tangible objects.

2.5.2 Principles of Learning related to Tangible Interfaces

Constructivist learning theory (Section 2.3.3) emphasises that designing and developing a representational model within a TUI is an productive and effective exercise for a student to gain both a knowledge and understanding of the interface and of the topic being represented (Marshall, 2007). An example of Papert's theory of constructionism occurs where children learn by actively building a physical construction that represents what they have learnt e.g. understanding chemical bonds in atoms could involve building atoms using balls and connecting straws. The actual process of breaking down the problem to create the model involves identifying and understanding of the processes, interactions and complexities of the underlying theory and concepts behind the physical model. The building process will cause the student to reflect upon how well the simulation compares to the real world, then problem solve to rectify differences.

Papert asserts that the construction process converts implicit knowledge to explicit (O'Malley & Stanton Fraser 2004). MIT MediaLab's Topobo (H Raffle & Garcia 2003) was designed using constructivist principles for a target audience of young children where it can be used to simulate behaviour of a dog doing tricks. A higher level cognitive example suitable for adults is a system of a surface with tangible objects to simulate a proposed design for a warehouse storage system (Lucchi et al., 2010).

Expressive tangible systems also known as Froebel inspired Manipulatives (FiMs)(Zuckerman et al., 2005), are advantageous for learning because they allow people to create constructions that may not be possible with traditional systems. Standard construction kits, such as Lego, do not have the coupling to digital data found in TUI (Price, 2004). This coupling potentially provides an opportunity to better represent ideas in physical form, than otherwise would be possible. The process of transposing an idea or concept into a physical entity (making abstractions touchable) demonstrates the learner's personal understanding of the concept and is a proven method for learning (Marshall, 2007).

There seems to be no definitive list of elements/attributes of TUI that are empirically confirmed as contributing to learning/comprehension in the published research (Antle & Wise 2013; Horn et al. 2011a; Marshall et al. 2007). The closest such list is detailed in (Antle & Wise 2013).

2.5.3 Learning through Collaboration

Learning in groups is a well-established successful educational technique (Ormrod 2004). This section reviews how collaboration has been applied in TUI, which provides and indication how useful it may be for learning about natural resources.

While discussing if Tangible Interfaces Really are Any Better Than Other Kinds of Interfaces? (Marshall et al. 2007, p. 4) propose their theory that:

> The real value of tangible interfaces may turn out to be largely in terms of how they can facilitate various kinds of collaborative activities – that are not possible or poorly supported by single user technologies.

This supposition is reinforced by the view of Robinson (2010) who states that 'Great learning happens in groups' and 'Collaboration is the stuff of growth'.

The contribution to learning from collaboration is significant (Ormrod 2004). Some students learn better working together with others than they do individually. Collaboration may be turn based or simultaneous (Fernaeus & Tholander, 2008). Many forms of TUI encourage or permit simultaneous interaction (Kirk et al., 2009). The multi-touch table music synthesizer ReActable is a perfect example. The ReActable is discussed in detail in Section 2.6.2 Interaction and can be observed in Figure 10.

Collaboration is not automatically successful as observed in the following example. A study by Stanton and Neale (Cited in Foster 2008, p. 133), reported that pairs of children collaborating using two mice showed a decrease in collaborative activity. This was believed to occur because frequently one student in the pair was observed to watch the other to see how they used the system, thereby disrupting the collaboration. Other negative impacts are observed with a multi-use, multi-touch system. In this example operators controlled their own work within stages of the program, but could not proceed to the next stage without forcing all the users to move to the next stage at the same time. In this case, his system works well when all the participants are communicating with one another and when they all work at a similar speed. It breaks down when participants operate independently and do not communicate.

Collaborative systems are generally more beneficial than single user systems, but they are bound by the personalities of the individuals in the group (Edge 2008). An individual who is not a team player will very well be detrimental to the group as a whole(Fleck et al. 2009). The same is true for a passive participant who may have much to contribute, but be too shy to be actively involved. Turn based collaboration (Fernaeus & Tholander, 2008) is one method that attempts to overcome personality impedances. These problems are independent of the interface.

2.5.4 How Tangible Interfaces suit Personalised Learning

Individual TUI are designed with a clearly defined single form factor. The form factor is evident in the following well known projects of the Tangible Media Group of the MIT MediaLab:

- I/O Brush - a handheld paintbrush that uses the world as the paint pot (O'Malley & Stanton Fraser 2004),
- Topobo – a robotic building block set that is able to store and play back movement (Hayes Raffle & Garcia 2003),
- Sandscape – a projected overlay on a sand box to provide true hands on understanding of landscape scenarios (MIT Media Lab 2012) and
- PSyBench - which allows collaboration between remote users via physical objects on a synchronised, projected augmented reality workbench (Edge 2008).

Each example system is a valuable tool well suited to its purpose. They are a good fit for personalised learning, where the student may choose their own learning methods. TUI offer an alternative to existing methods of learning because their inherent haptic nature adds a kinaesthetic perspective (Etemad 1994; Lujan & DiCarlo 2006b). TUI have a home in personal learning as one part of the teaching process.

2.5.5 Do Tangible Interfaces Enhance Learning?

It is worth reviewing the Marshall (2007) paper – *Do tangible interfaces enhance learning?* as it is cited by many paper based studies on TUI learning (Fernaeus & Tholander 2008; Lucchi et al. 2010; Price 2004; Shaer & Hornecker 2010).

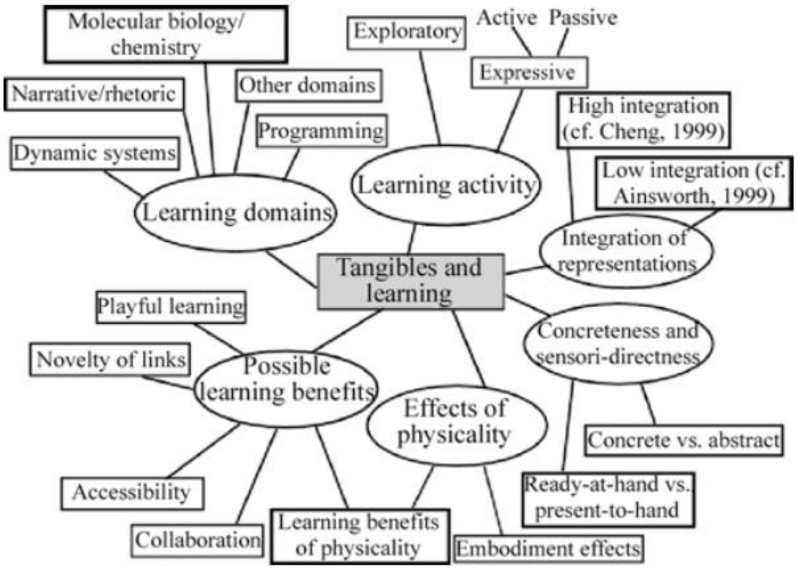


Figure 9: Analytic framework on tangibles for learning [Marshall, 2007].

(Marshall, 2007) proposes an analytic framework (Figure 9) on learning with tangible user interfaces from detailed evaluation of the characteristics of essential elements of both tangibles and learning. The framework specifically focuses upon the key elements of the contributing perspectives: Learning domains, learning activity, possible learning benefits, effects of physicality, concreteness and integration of representation. The framework hints at the complexity of mapping the full interplay between learning and tangible interfaces. It illustrates that TUI show great promise as a teaching tool, if balance is achieved. The framework is a valuable summary of the many contributing aspects of tangibles and learning.

The framework author is explicit in pointing out that this framework 'outlines six major themes that need empirical testing and further theoretical development' (Marshall et al. 2007, p. 2). It is important to note that some of the branches of the themes have theoretical basis for inclusion, but have little or no empirical evaluation. Others have empirical results; however these results have raised fundamental questions, or do not clearly show a benefit over present popular systems. For these reasons the framework represents a concise guide for future work themes.

The six major themes are split into three groups focused upon learning, plus three groups focused upon the design of the elements of the interface. This arrangement reinforces the balance between learning components and the elements of tangible systems suited to learning.

The sections on learning are:

1. How learning might be acquired (Possible Learning Benefits),
2. Applications created for TUI (Learning Domains) and
3. The method with which the operator engages the interface to attain knowledge (Learning Activity).

The interface design themes are:

1. Degree of physical human embodiment (effects of physicality)
2. Linkage between tangible objects and digital artefacts (integration of representations) and
3. How well interface objects behave to the operator and also engage the operator (concreteness and sensory directness)

The diagram (Figure 9) shows these six components all contribute to the construction of a successful TUI, not one solely developed for teaching. A TUI designed to educate should obtain suitable specifications in each of the six themes in order to provide a positive learning benefit. Even the elements within the possible learning benefits will influence the overall outcome.

Marshall et al discuss two forms of tangible technologies for learning: expressive and exploratory. They draw upon a concept from the philosopher Heidegger, termed *readiness-to-hand* (Heidegger 1996) later applied to human computer interface design by Winograd & Flores (1986) and more recently to tangible interfaces by Dourish (2001). The concept refers to the way that when we are working with a tool (e.g. a hammer) we focus not on the tool itself, but on the task for which we are using the tool (i.e. hammering in a nail). The contrast to *readiness-to-hand* is *present-at-hand* (i.e. focusing on the tool itself), which would distract from using the interface for its purpose.

2.5.6 Knowledge Gaps in Hands-on Tangible Interaction Research

Most current work in the field still invokes high level theories to explain possible learning effects without empirical validation (Antle & Wise, 2013). There exists a knowledge gap of limited research on TUI for Adults (Antle, 2012). While a large number of peer-reviewed papers advocate TUI has sound potential for learning, only a small percentage are empirical studies (Antle & Wise, 2013). Few of these studies focus on adult users, while fewer still focus on learning. Little empirical research exists showing uptake, user engagement, or use preferences for adult users of multi-touch tangible systems (Antle & Wise, 2013; Schneider et al., 2010) with the majority of past research for tangible objects focusing on children (Marshall et al., 2003;Price et al, 2008; Zuckerman et al., 2005). Antle (2010, p. 233) notes that "Despite a long history of hands-on learning with physical and computational materials, there is little theoretical or empirical work that identifies specific causes for many of the claimed benefits. ".

Two of the recognised gaps targeted in this thesis are :

1. "There continues to be a lack of theoretically grounded guidance for designers as to what design choices might be expected to have significant impacts." Antle & Wise (2013), and
2. "One area that may be revolutionized by tangible and touch technologies is hands-on problem solving in spatial domains." (Antle, 2012, p233)".

2.6 Interaction Design Characteristics

The review thus far indicated the appropriate TUI for the research purpose, however it has not addressed how natural resources will be applied in the system. Constructivist learning has been suggested for the teaching component. Nevertheless, a touch table system must have a custom interface for such a research purpose. This section examines design characteristics that should be considered in the development and construction of the tangible touch table interface.

2.6.1 Interface Design

The TUI interface design and interface functions must meet a balance. A balance exists between being too easy to use and being too difficult to understand. Balanced systems should be designed until more research is conducted to clearly define the circumstances where complexity of the interface is linked to success in completing goals.

A debate rages as to whether intuitive easy to use interface designs, or difficult to understand interface designs, are better for learning and problem solving. The design elements of metaphors and the aesthetics of the tangible objects affect the level of complexity of the design of the interface. The representations and metaphors in a tangible user interface design provide significant contribution to the overall ease of use of the interface. The metaphor of objects (i.e. the resemblance of interface objects with their real world counterparts), paired with the semantic directness (the resemblance of interface objects to the users intent E.g. floppy disc icon for save) influences how well users interact with the system.

Easy to use interfaces possibly make us complacent. O'Malley & Stanton Fraser, (2004) report that research shows 'transparent or really easy-to-use interfaces sometimes lead to less effective problem solving.' This is substantiated by Marshall, (2007) who asserts 'The easiest to use or most concrete interface does not necessarily lead to the greatest performance in problem solving and learning'. The justifying argument is that the mind is not engaged because the operator does not have to think about the interface, therefore they will not think creatively when the interface is applied. The author believes that concrete interface elements look and appear complete because they have sufficient detail to be perceived by human nature to be a finished product, whereas a hard to use interface, or rough representation, is clearly not a finished product thus encouraging the mind to fill the gap, consequently demonstrating problem solving and learning.

Complex interfaces are inefficient and frustrating (Sharp et al. 2011) . In an abstract, or difficult to use interface, users become confused using the interface. They do not have a working knowledge of the interface, so they are restricted in how they can apply the program, thus their results will be diminished. A user still may know what they want to do, but not be able to do it because of a difficult to use interface (O'Malley & Stanton Fraser, 2004). This may well be true for novices. People with limited experience in the program will focus on learning the interface, rather than completing their work that must be undertaken using the program. However, an experienced, or expert, user is highly efficient in using the interface and can produce higher quality output simply because they know how to most effectively use elements of the program. This is in contrast to a novice who will produce output using restricted functionality working only within their limited knowledge of the interface. A common example is Blender, an open source 3d modelling program.

A complex application will likely have a complex interface (Benyon 2010). An easy to use interface is not the most efficient use for an expert, or experienced user, however it may allow novices to work in a knowledge domain where they do not have experience or expertise. A good example is the field of Computer-aided Design (CAD). Originally, CAD was solely the domain of experts in construction and design (Architects, Engineers and Draftsmen), but is now accessible to the general public via easy to use limited function interfaces. Is this wise?

‘If you close it all in and specify everything there is no room for the imagination to play. You must leave big enough holes for the imagination to play.’ (Buxton 2007, p. 407) Buxton’s statement may be more of a comment aimed at the design of applications, rather than poignantly aimed at learning applications where it would disagree with research by (Marshall, 2007, p. 167):

> Interfaces that constrain the ways that learners can use them or which introduce interaction costs can lead to increased planning and reflection, which can in turn lead to improved learning. It is possible that if tangible interfaces support easy manipulation of concrete objects, that they could in turn lead to decreased reflection, planning and learning.

Marshall’s counter argument is an inference using a known result to imply the opposite could be true. As yet, there is a no empirical evidence to justify this inference, which is why Marshall, (2007) qualifies it by starting with *It is possible tha*t and including *could lead t*o. Still, Marshall’s suggestion in his highly cited paper has the effect that it brings into doubt positive benefits of intuitive, easy to use design, within a tangible interface. This side of the debate as presented by Marshall (2007) make it difficult to determine which elements contribute to learning. It needs to be acknowledged that Marshall (2007) is frequently cited as validation in the opposite of the conclusions of the paper.

The debate continues and requires empirical evaluation to determine the best level of design for progress and efficiency (Heijboer & Van Den Hoven, 2008). ‘The point is to channel the learner’s attention and effort towards the goal or target of the learning activity, not to allow the interface to get in the way.’ (O’Malley & Stanton Fraser, 2004, p. 4). It is this author’s opinion that an intuitive natural user interface is a better system for both learning and general productivity. The interface should aid, not detract from, the user experience.

2.6.2 Interaction

The number of available interactions in TUI depends upon the design of the interface and its purpose. Physical interactions can take the form of any manipulation that is possible with everyday objects, such as: squeeze, pat, poke, lift, push, rotate, move, place, stroke, pinch and stretch. The range of interactions is greater when using more than one object because the set of interactions includes those generated by proximity of objects to one another. A proximity interaction may be triggered by objects being too close, or too far away from each other, or by the orientation of one object within a set distance to another, or even by the current value of objects within proximity. Proximity applies in object to object, object to virtual and virtual to virtual interactions, or even extends to tangible augmented objects. The variety of available interactions increases as the number of tangible objects increases simply because of the number of permutations of possible interactions available.

The ReacTable is a good example of the variety of tangible interactions in operation. The ReacTable is a music synthesizer designed upon a projected multi-touch table, which is controlled by tangible objects termed pucks (O'Malley & Stanton Fraser 2004). The table is designed to be used collaboratively, or individually. The music starts by placing a puck on the surface. The pucks have six different shapes reflecting the different synthesizer roles: audio filters, audio generators, control filters, controllers and audio mixers. The pucks interact with each other based upon their proximity to one another. The tabletop shows a constant visual representation of the interactions between all the pucks. Rapid, real time adjustments are controlled by twisting, sliding, reposition, removing, or flipping the pucks. The system shows the actual wave form passing between the pucks as seen in Figure 10. The waveforms may be changed by drawing a new waveform next to the one to be replaced. The ReacTable system is very dynamic and flexible, yet it is robust and easy to use.

Figure 10: The ReacTable, a musical instrument controlled by tangible objects.

Although there are a large number of possible interactions in TUI, many are repeated within the range of TUI applications. This repetition, inspired early work by Shaer et al, who suggested the Token And Constraints (TAC) paradigm to define interactions in TUI (Shaer et al., 2004). 'A TAC (Token And Constraints) is the relationship between a token, its variable and one or more constraints.' (Shaer et al., 2004). A token is a tangible object, a variable is the relationship controlled by the token and the constraint is the physical limiting factors. In an example of playing chess with real chess pieces on a touch table, the token is the chess piece, the variable is the chess move triggered when the chess piece is moved and the constraint is the physical extent of the touch table. The TAC paradigm was created as a precursor to the development of a high level TUI programing language centered upon the defining elements of their interactions. This is an attempt to standardise the elements of TUI.

2.6.3 IntePhysical – Digital Coupling

Physical to digital coupling means: when tangible objects are used with an interface that the interface shows a response on a digital display (Holmquist et al. 1999). In the case of tabletop displays the response is typically a graphic, sound effect, animation or combination of such.

The real value of the coupling is that it extends the experience from one sense to multiple senses; from the haptic senses of texture and weight to visual and audio stimulation. Lujan & DiCarlo (2006, p. 15) research shows 'Students prefer concrete multi-sensory experiences in their learning' which is reinforced by Shams & Seitz, (2008, p.5) who believe 'multisensory training can be more effective than similar unisensory- training' because ‘other studies suggest that multisensory exposure enables stimuli to be encoded into multisensory representations and thus will later activate a larger network of brain areas than those invoked after unisensory encoding,’ (Shams & Seitz, 2008, p.7).

One of the difficulties with tangible objects within a TUI design is that ‘the perceived coupling between physical and digital representations is not always straightforward’ (Price et al., 2010). Hornecker & Buur, (2006) and Price et al, (2008) note both the significance of adept representation and the difficultly of achieving it. Choosing an object to represent a digital function is akin to Pictionary – there is every chance that some people will not understand the purpose of an interface object as easily as others. The selection process a user makes when choosing a interface element is inherently linked to cognitive load (Hollender et al, 2010) so the preferred choices are objects that ideally represent their purpose, as these have the lowest cognitive load. Therefore it is important to evaluate any couplings in the interface to ensure they are understood by the target audience.

2.6.4 Representation

Representation is the design of a physical object, the look, feel, colours, smell, texture, abstractness, and weight. Representation needs to consider the degree to which it matches its purpose (Kirk et al. 2009). Representations are ‘a thing, especially a picture or model, that depicts a likeness or reproduction of someone or something’ (‘Definition for representation - Oxford Dictionaries Online (US English),’ 2012).

General research on representation is a popular topic in TUI research (Speelpenning et al. 2011) and is also well established in design principles (Resnick et al. 1998; Dourish 2001). Representations encourage engagement, however it is the way they are presented and supported determines their effectiveness. ‘The representation of a task can radically affect reasoning abilities and performance’ Zhang & Norman (1994). Zhang and Norman conducted a series of experiments on variations of the Tower of Hanoi to measure the effect of external representation (the way a object is designed so that it physically encompasses rules governing its use. i.e.. 2 litre plastic milk cartons are exactly the width of a fridge door shelf and they have optimally positioned moulded handles).

(Zhang & Norman, 1994) evaluated players’ performance using tokens that were modified so that the tokens must follow the rules of the game and were designed so that their purpose was intrinsic. The experiment used a set of tokens where each token was designed to incorporate progressively more rules of the game. The players were only told the rules that were not built into in the game pieces in use. The results clearly showed that the players performed progressively faster and with fewer errors, as more rules were incorporated into the external representation (token)(Zhang, 1994). Logically this makes perfect sense because if the tangible object is designed to accommodate a rule, then it becomes a physical impossibility for that rule to be broken by anyone using the object. External representation also gives the operator fewer rules to remember. Consequently, it would be good practice to design representations to embed as many rules as viable.

Are metaphors a good thing? Streng et al. (2009) note that some researchers, including Gorbet, argue that metaphors restrict the thinking of the operator(Gorbet et al. 1998). Gorbet testifies that TUI's with no metaphors are better because they do not impede the operator's thought processes, thereby improving creativity and problem solving. This is in opposition to Koleva et al. (2003) who determined that strong metaphors create a higher degree of coherence between physical and digital objects, offering advantages for successful interaction. Interaction is fundamental to tangible interfaces, as is clear thinking, planning and problem solving.

Fishkin (2004) developed a taxonomy for TUI using metaphor and embodiment. The classification system is straightforward and creates a logical differentiation. It provides a method to identify and compare like systems to like systems. Interestingly, the Fishkin Taxonomy groups together TUI that do not obviously share similar properties. This is demonstrated by applying this taxonomy to Illuminating Clay and Topobo, two functionally distinct tangible interfaces - both are defined in the same category (full embodiment and the full metaphor). The contrary findings demonstrate that there is still plenty to learn with regards to metaphors in TUI (Fishkin 2004; Streng et al. 2009).

It is worth considering the studies on physical objects and learning for mathematics, as they correlate well to characteristics of tangible objects. These studies do not use any form of computer software, or hardware. They just use physical objects. The studies investigate learning basic counting and arithmetic.

A research study in 1995 on young children to learn mathematics by manipulatives (physical objects used to promote hands-on learning e.g. Cuisenaire Rods), showed that the manipulative objects were not effective tools for learning (Zhang & Norman, 1994). The researchers hypothesised that the use of tangible objects would improve the students' mathematical abilities. The negative results occur because the children did not perceive that the objects represented a mathematical quantity. They did not understand the 'blocks' intended use, so they used them how they thought they should be used, which turned out to be less effective. This is an example of poor representation. A review of literature on learning in mathematics five years later (Uttal, Scudder, & DeLoache, 1997), showed the opposite result – Children who used manipulatives received higher grades than those who did not. The review attested that the children need to be informed about both the purpose (why) and function (how) of the objects in order to use them effectively. Equally importantly the practical tasks must suit the topic (what) and finally, the What, Why and How must be make sense to the student in the context of the class. When applied correctly, manipulatives were found to increase learning and be a valuable teaching extension aid.

It is interesting that in the above example, that the students did not perceive how the objects should be used. This shows that the Cuisenaire Rods had a very low level of affordance, however the meaning and purpose was understood once explained. Further research showed that pictures and photos were found to work equally as well as manipulatives, which is possibly a result of the preference of the visual learners. It implies that GUI and TUI were equally worthwhile in non-technological form.

Extensive empirical research by DeLoache noted by (Uttal et al., 1997), on the understanding of symbology by very young children, proves that very young children do not understand the representation of highly realistic objects. Children focus more on the object than on what it represents (Uttal et al., 1997), possibly because they find the object itself engaging. It should be noted that these experiments were conducted on children, less than 5 years old and 15 years ago. Children today are bombarded by stimulation and children in this age group know how to use the touch interface of smart phones and tablets. Albeit not always for the right reasons (iPad babysitter your-babysitter-an-iPad (Pierce 2011)), however, it implements peace in the doctor's waiting room.

Older children and adults readily assign a mental model to graphical, or physical, element in an interface (Sharp et al. 2011). They have expectations of what will happen when an icon is clicked or a controller moved. The experiment by Uttal et al. (1997) is significant because the empirical conclusions provide some guidelines for designing tangible objects in TUI. Heijbour and Van Den Hoven (2008) test the affordance of the visual appeal of tangible objects used in a game and also compare the responses of adults to children. Their research question is *What is the effect of different levels of abstractness on the interpretation of game artefacts?* The experiment was designed as a tangible touch table game. Each player had a series of game tokens, which were progressively more detailed. The low fidelity pieces had less functionality, than the high fidelity play pieces. The players were not initially told what level of functionality was attributed to each play piece. Their play was observed and the participants were interviewed after the game was over. The experiment subjects varied in age from 10 to 53.

The results showed that:

- The study found that all participants noted that they found it easier to differentiate game objects based upon colour or size, than shape (Heijboer & Van Den Hoven 2008).
- Their perception was that the functionality increased with the detail of the artefact. The participants perceived that the simple and abstract pieces would have simple functionality, while they expected that the highly detailed pieces would have a high level of functionality.
- There was also no significant difference in interpretation of representation between children and adults.
- The player's first interpretation of an artefact 'is mostly based on visible references' (Heijboer & Van Den Hoven 2008, p. 8)

Few people have experienced exposure to tangible Interfaces, although they are becoming more common (Sharp et al. 2011). In this case users do not have a good mental model of the purpose of a tangible interface object. Their expectations may be biased and restricted, by their experiences of smart phones/tablets, so that their expectations are limited to expecting feedback of some kind that informs them what to do next, be it a menu, graphic, sound, or an animation. Personal experience indicates that the more basic the representation the greater is the degree of unknown about what it will do in the interface. A high fidelity tangible object is more useful in that the detail of the representation implies some information about its purpose, however broad as shown by (Heijboer & Van Den Hoven, 2008). Consider an interface tangible object that is a cube. It has a low level of affordance and the cube's function may only be understood by knowing the purpose of the interface. Additional information from the interface will point to its use. Changing the physical representation, by increasing the detail to a figure of a person implies that the function is going to involve something about people, thus eliminating many other potential purposes (e.g. so it will not be used to create roads). Increasing the detail even more, say to a policeman, offers more clues to the use of the tangible object. Higher detail may assist determining what an object may be for, but it does not necessarily help with implying how to use it. Ideally the representation should infer how the tangible object should be used. Perhaps standards should be developed for representation for interface objects in a similar vein to the Touch Gesture Standards (Wroblewski et al. 2010), while the field is still young.

More empirical research needs to be undertaken to assist in defining classes regarding the degree of representation and its impact on a range of users and application domains.

2.6.5 Tangible Objects may Replace Touch Functions

Touch control is a common and often preferred interface control mechanic (Xie et al. 2008). The influx of phones, tables, touch pad on laptops, Navman, handheld games and information kiosks have provided much of the community with touch control skills. Furthermore it has embedded the use of touch as a naturally accepted and expected way to control interfaces.

However, sometimes objects work better than touch because they are better adapted to suit the purpose (Gentile et al. 2011). They trigger emotional attachment (Shamonsky 2003) or they have greater appeal. An ideal example is using a paintbrush within a drawing program on a touch table (Figure 11).

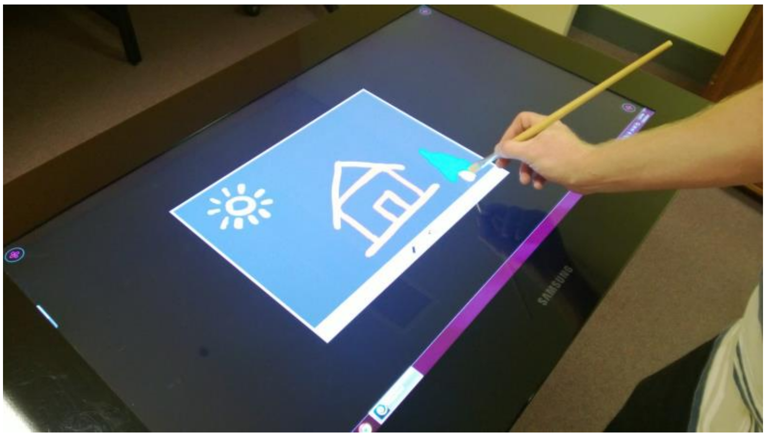


Figure 11: Using a standard children's paintbrush with a drawing application on the PixelSense.

In this example the painting program was developed to work as a touch only application. It required no coding enhancement to work with the paintbrush. The paintbrush was used on the PixelSense in an exercise with the general public on a University of Tasmania Open Day. Attendees were encouraged to draw using their fingers, when they finished they were offered the opportunity to use the paintbrush on a new canvas. Observation showed paintbrush users were more focused, spent longer on their drawings, more completed their drawings and more wanted a copy of their completed drawing. The drawing application was the most popular application on the PixelSense. Throughout the day attendees queued to use the paintbrush. Many did not use their fingers to draw at all, preferring to use only the paintbrush.

The paintbrush was described by the participants as the perfect object to use for painting. Almost everyone knows how to use a paintbrush. The paintbrush worked seamlessly with the hardware and software. It triggered positive feelings and memories. Many users commented upon their fond memories of using a paintbrush from childhood. It inspired cultural use from the Chinese adult users, who mostly used the paintbrush for calligraphy to draw the symbol for Dragon.

The paintbrush appealed because of the emotive linkages, the ease of use and fit for purpose.

The exercise using the paintbrush demonstrates the gains and advantages possible when an ideal object is selected for interface design. The experience shows using the right object at the right time for the right purpose will achieve a high engagement, high use, high task completion and repeat use. It is an excellent example of successfully applied representation (Section 2.6.3)

2.7 Natural Resource Considerations for TUI

Present natural resource information systems contain a variety of styles of data and analysis tools. The data includes financial information, reports, resource information databases, GPS logs, remote sensed images, air photography, satellite imagery and spatial data. In a present day scenario where natural resources information is presented to a group meeting, the relevant information is stored on a central computer which uses a standard projector to display the information a wall (Scotta et al., 2006). The central computer has the required software to show the data in appropriate context, meaning that GIS data is shown using a GIS, financial information is shown using spreadsheets, database information is shown in form or report view, etc. Often the digital information is supplemented by posters, reports and large format maps.

A review by Scotta et al, suggests that tangible multi-touch tabletops (touch tables) offer a viable alternative to the present traditional method. 'The concept of tangible user interface (TUI) seems the ideal solution for discussion groups' (Scotta et al., 2006). Scotta et al reviewed the TangiTable and the MapTable. The TangiTable used by the model and design business RoVorm, to perform pre-set GIS actions displaying results projected directly onto a table. The pre-set actions are controlled by placement of coloured tangible objects discs to activate spatial actions such as zoom, query and flyover. The configuration of the system consists of a camera and projector suspended directly above a table. A computer interprets the camera feed to detect the discs. This informatiom is sent to the GIS which processes the appropriate GIS action. The result is projected upon the table. The system is seen in action in Figure 12. The coloured boxes on the left hand side provide map information requested by placement of the matching coloured discs.

Figure 12: The TangiTable in action . The red, green , and blue discs activate GIS actions on the map.

The TangiTable only has basic map functions. It is not capable of performing medium or complex analysis, therefore it is not capable of answering anything more than basic queries.

Another example, The MapTable is used by the Dutch ministry for transport, public works and water management to evaluate the impact of changes to town planning boundaries. The system is based on a table because the work purpose involves consultation with local experts and the table is thought to aide the discussion process. The control is a hand sized stylus so changes are drawn directly on the map on the tabletop. These changes are processed in a town planning mapping GIS model and the results are displayed within a short time. This system uses a camera and projector system similar to the TangiTable, yet this version is designed for portability. The MapTable is capable of advanced GIS analysis, but is only designed for one clearly defined purpose, hence is very limited in its applicationDespite their limitations, both systems show the potential for this form factor to meet the needs of a natural resource interactive system.

Limited functionality is sometimes all that is needed for a fully functioning system. The early TUI development work of the GeoTUI system is a good example of a simple system successfully suiting a complicated task. GeoTUI is used by Geophysists for planning cutting planes on a subsoil map. A standard map of subsurface soil profiles is projected upon a table (Figure 13) which uses a ruler as a tangible object to select the appropriate cutting plane. The ruler is linked to software for the manipulation of 3D volumetric geographical subsoil models which tracks the ruler and updates the map to the next subsurface profile.

“The major idea is to use a tabletop vision-projection system and props as tangible user interfaces that can be manipulated directly on any suitable table (see Figure 12). In this way, we combine the horizontal working conditions (that the geophysicists are used to when working on a desk) with the use of powerful geological simulation software. Moreover, by using the props directly on the table, the geophysicists interact in the same way as in the classical paper map environment.” (Couture et al. 2008, p.90)

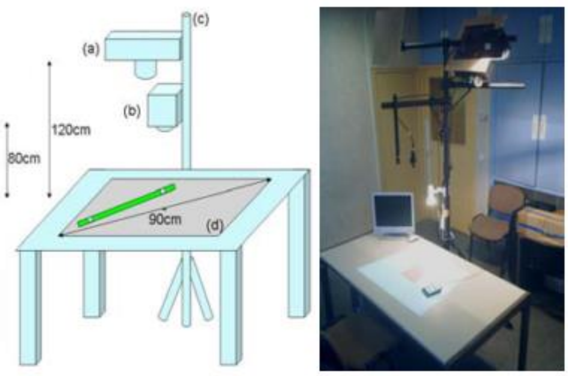


Figure 13: The setup of the GeoTUI sytem.

The user study compared the traditional system using a mouse with GeoTUI. The tasks were real world practical tasks using factual subsoil maps. The within-subjects study used 10 participants for two days. The participants completed a qualitative questionnaire which was assessed user preferences. The tasks were times and observed by the investigators. The comments showed that they preferred to use the tangible system as it seemed more natural than the mouse based system. They also felt that the work was quicker and more effective. The quantitative measures showed that the tangible interactions performed quicker and more effectively than using a mouse and keyboard (Couture et al., 2008). The Geophysists benefited from the tactile response and direct control available by using their hands in a tangible user interface.

A disaster management application is a close match sharing many common features to a natural resource application. It is worth reviewing disaster management TUI since there are few natural resource TUI, apart from game simulations (Antle et al., 2011). One such system is the Multi-User Tangible Tabletop Interface (MUTI) (Hofstra et al., 2008). The MUTI system acknowledges that tangible objects are integral in these circumstances, as users have 'natural tendencies to reach, touch and grasp.' (Hofstra et al., 2008). However, the MUTI system takes an opposing view on the use of tangible objects to traditional tangible systems. MUTI has been designed to allow objects to be placed upon the interactive surface as dormant elements that have no effect on the interface, thus permitting operators to write notes and draw diagrams on physical paper/notepads without triggering unwanted effects. This non-interaction of tangible objects is the natural workflow in this style of work. In a group situation a large printed map laid on a table immediately sparks interaction and collaboration. People are drawn to the map, talking and pointing. Frequently these collaborators use supporting information to make their point. This information takes the form of smaller maps, reports, photos and post-it notes. Although worth considering from a natural workflow perspective, MUTI, could benefit if it was able to accept limited tangible object interaction, while still allowing notepads and reports to be used on the tabletop, that way MUTI would have the most effective features of both worlds.

The TanGeoMS system discussed in Section 2.4.4 by North Carolina State University extends the Illuminating Clay project by linking to a Geographic Information Systems (GIS). The researchers call this system Tangible Geospatial Modelling (TanGeoMS).

2.8 Summary

This chapter presents a case for why an understanding of natural resources is critical to various areas of decision making and policy. It then showed that present methods still lack a comprehensive solution. Emerging mainstream technology offers a solution to this issue, as it is engaging, memorable and educational (Hornecker & Buur 2006).

The spatial nature of natural resource information lends itself to a map-based solution. Review of adult learning preferences and learning models indicate constructivist tasks as likely to encourage learning (Knowles et al. 2005; Piaget 1962; Rick et al. 2009).

The literature review along with the spatial nature of natural resources and the preferred learning mechanisms for adults, indicate that an Interactive Map-based tangible touch table system using constructivist learning tasks could improve understanding of natural resources.

The literature review points to this area as being under developed, particularly with regards to empirical information, as noted by Antle (2012, p. 234) 'Most current work in the field still invokes high level theories to explain possible learning effects without empirical validation'.

The hypothesis for this thesis is:

A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources

This hypothesis contains the following research questions:

1. *What is required for comprehension of dynamics of natural resources?*
2. *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources*

An empirical study investigating TUI for adult learning to improve understanding of natural resource issues will extend existing knowledge about TUI, and extend knowledge outlining how TUI contribute to raising awareness of natural resource issues which addresses the current gap in TUI research.

Chapter 3: **Research Design**

'Research is formalized curiosity. It is poking and prying with a purpose.'
Zora Neale Hurston

3.1 Introduction

The literature review argued that a multi-touch table tangible system using Interactive Map-based constructivist exercises are a solution to encouraging understanding of natural resources to adults.

This chapter describes how the research requires three stages, then breaks down the research methods and experimental design for each.

It begins by defining the elements of the hypothesis. This is followed by a detailed description of each stage describing contribution to the research, participants, measures, assessment, and analysis. The research design includes:

- compilation of natural resource issues and knowledge gaps by semi-structured interviews with natural resource experts,
- identification of features of Tangible User Interface (TUI) that benefit learning,
- participation design with community groups and
- the main within subjects exercise at a public forum.

Each exercise follows a similar format as other TUI comparative evaluations in peer reviewed papers.

The chapter finishes with potential limitations.

3.2 Hypothesis and Definition of Terms

The hypothesis is:

A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources

This hypothesis contains the following research questions:

1. *What is required for comprehension of dynamics of natural resources?*
2. *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

The hypothesis is comprised of three significant terms:

1. Tangible User Interfaces,
2. Map-based constructivist learning techniques and
3. Understanding of natural resources.

These terms are defined clearly below, with the interpretation used in the context of the proposed study:

- Tangible User Interface (TUI) : Webster's Dictionary Online (2011), defines a TUI as 'a user interface in which a person interacts with digital information through the physical environment'. Ishii states 'Our goal in TUI development is to empower collaboration, learning and design by using digital technology and at the same time taking advantage of human abilities to grasp and manipulate physical objects and materials.'(Ishii 2008, p. 1). The thesis focuses specifically on the instance of a tangible user interface where tangible objects are placed upon and interact with, a tabletop. This research is limited to tangible objects that are solid, non-actuating, do not contain electronics, nor directly control electrical interfaces. The tabletop has the capacity to detect tangible objects, as well as multi-touch gestures from two or more operators using a minimum of two fingers per person.
- Constructivist learning: 'Constructivist teaching is based on the belief that learning occurs as learners are actively involved in a process of meaning and knowledge construction as opposed to passively receiving information. Learners are the makers of meaning and knowledge. Constructivist teaching fosters critical thinking and creates motivated and independent learners.'(Gray 1997, p. 1)
- Map-based constructivist learning techniques: Using a digital Interactive Mapping environment where adults learn by applying real world examples with existing datasets in local context.
- Natural resources exist inherently within the environment. Minerals, flora and fauna in their natural state are considered natural resources.

- Understanding of natural resources in this context refers to the process by which one natural resource depends upon another which is a fundamental economic concept known as interconnectedness (Cudmore 2009). 'The existence of interconnectedness explains why when changes are made in one part of the ecosystem, other components are affected, often in unexpected ways' (Cudmore et al, 2009, p. 5).

3.3 Theoretical Framework

The research method is based upon the theoretical frameworks of:

- Constructivist learning [spatial reasoning/reflection/collaborative interaction]
- Cognitive load theory and
- Domain Specific Context

Cognitive load is defined by (Oviatt 2006, p. 871) as "a global term, which refers to the mental resources a person has available for solving problems or completing tasks at a given time." Cognitive Load Theory describes the manner in which this mental effort is distributed (Hollender et al. 2010). A domain specific context is a clearly defined field of knowledge focused upon a finite topic.

3.4 Methodology Overview

The research project uses a design research methodology refined by participatory action research with industry and established community groups (Starcic et al. 2013). The results were measured using a mixed methods approach (Oates 2006). The mixed method approach allows both qualitative and quantitative methods to be applied in the research. In this way, the most appropriate method can be used when required.

The project was undertaken in three stages:

1. The first stage was a semi-structured interview of natural resource experts designed to obtain information to help answer the first research question *What is required for comprehension of dynamics of natural resources?*
2. Stage two evaluated elements of TUI interactive technologies to identify components most suited for the research purpose. This search concentrated on components with the most potential for adult learning, with natural resources.

This evaluation takes the form of a review of empirical and theoretical TUI studies. It was followed by trial preliminary implementations of the selected TUI components evaluating for appeal to general public adult subjects. The trials were evaluated based upon suitability, usability and engagement. The outcomes were used to determine the specific type, style and detailed design characteristics offering the most promise to encourage comprehension of natural resources by adults.

The second part of stage two advanced the design of the final application by consultation with industry and community groups (people directly affected by the natural resource issue) to incrementally refine learning requirements, priorities and implementation methods. This stage identified potential mechanisms to encourage comprehension of natural resources for adults.

3. The final stage was to conduct user testing to evaluate the features of a purpose developed natural resource user interface that specifically incorporated optimal design characteristics from stage two, to meet the needs of the dynamics outlined in stage one. The results combined with outcomes from stage two answer the second question: *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

These stages were implemented sequentially.

3.5 Research Design[1]

3.5.1 Stage One

This stage investigated all the natural resources aspects of the study. It investigated the following: underlying perception of the understanding of the general public; the most significant natural resource issues; knowledge gaps, real world examples that explained the gaps; and defined basic requirements for reasonable understanding of the identified issues.

---

[1] This research has a low ethics risk as defined by Human Research Ethics of the University of Tasmania. Ethics was granted accordingly.

The aim of this stage was to identify natural resource dynamics that would benefit from greater understanding and dissemination within the community. One of these dynamics was then to be chosen as the topic for the final TUI application of the research.

Secondly, the research set out to determine the defining requirements of the term *encourages understanding of natural resources*. These parameters were obtained by questioning experts to identify what should be understood. The responses provided a reasonable minimum level of understanding (facts and theories) required to demonstrate some understanding of the concepts in the stage one expert opinion.

The same process was used to quantify the underlying perception that the general public struggle to understand the dynamic nature of natural resources specifically the way that changes in one natural resource influences another in direct and sometimes indirect ways – from the stage one experts' perspective.

Importantly, the starting point for stage one was to identify the current natural resource issues most significant to Tasmania, because current significant problems should elicit the most relevance to and attached meaning for the target audience.

3.5.1.1 Semi-structured Interview of local experts

A more balanced approach, than a desktop review, is to ask those who are affected by natural resource issues in a professional capacity, preferably experts with extensive experience. A qualitative semi-structured interview of such experts suits the purpose well ensuring that all subjects are asked the same questions, yet have the flexibility to reply in their own terms supplying more or less information as their own expertise dictates (Oates, 2006). The semi-structured interview provides comparative qualitative data. A minimum of 15 subjects is needed to reflect the views of the population (Sokal & Rohlf, 1995).

The natural resource expert semi-structured interview aims to obtain information about real world examples, key principles, overall take home message and essential elements of the natural resource problem that should be known but are not generally well understood. Some responses provide the foundation to define the boundaries for the study. Other questions seek information about knowledge gaps, specifically the key elements for understanding the natural resources issue, which address the requirements for how the *comprehension of dynamics of natural resources* are determined. The responses from the semi-structured interviews contribute information to answer the first research question.

The results from the experts supply three sections of information that define the boundaries for the study:

1. identification of specific instances of *Dynamics of Natural Resources* that are a significant natural resource issue potentially suitable for the study,
2. a breakdown of the facts and concepts that underlie these instances, along with relevant experts, location of datasets and real world examples. The breakdown when combined with results from stage two, provides sufficient information for development of a method to meet the *comprehension of dynamics of natural resources* requirement of the study and
3. the definition of levels of understanding representing depth of knowledge, where the lowest level is the simplest view, while the highest level is a detailed knowledge and understanding of the interconnectedness of elements within the instance of *dynamic of natural resources*.

The interview was conducted primarily in–person at the offices of the participant, because it 'puts the interviewee at ease because of the familiar surroundings and is in context of the interview topic' (Sharp et al. 2011, p. 237). Also, the interviewee is less inconvenienced and has access to his or her own supporting material, if required. Participants outside of Launceston were interviewed by telephone.

All interviews were recorded for audio to ensure accuracy of transcription of responses.

3.5.1.2 Participants for Stage One

The aim of the first stage of the research was to identify natural resource dynamics that would benefit from greater understanding and dissemination within the community. The participants in stage one were adults who have extensive experience in natural resources - preference was shown to those who currently work in natural resource disciplines. Participants were preferred to have a minimum of 3 years work experience with natural resources involvement.

The study requested a participant from each of the main organisations that make extensive use of natural resource information, refer Figure 14. Participants were sourced from, but not restricted to, the following organisations: NRM North, federal government, state government, local government, environmental consultancies, UTAS, Environment Tasmania and volunteer natural resource organisations. Using a broad selection of agencies as a pool for participants was intended to ensure a balance of viewpoints reflecting the views of the whole population of natural resource experts. Representative were included from organisations that significantly impact the environment, both adversely and in a supportive role. The pool of participants ideally included participants from traditionally opposing viewpoints and perspectives, such as Forest Industry and Conservation, in the interest of balance. A minimum of 15 participants was required as this is the smallest sample meeting the requirements for qualitative analysis (Guest et al., 2006), however a sample of 20-30 was preferred.

Potential candidates were approached to participate in a semi-structured interview.

Figure 14: Tasmanian Organisations involved with Natural Resources

3.5.1.3 Assessment - Questionnaire Design

The semi-structured interview questions were a mix of open and closed questions.

Initially all the questions were designed as open questions because they are 'especially useful for questions when you realize there is a wide range of possible answers, or you do not know how the respondents are likely to answer' (Oates 2006, p. 223). Open questions encourage flexibility with answers in the respondent's own words. However, time constraints by the experts limited the time available for interview. Preliminary consultation with potential participants indicated the interview session length should be no more than one hour – including project brief, all questions and all post interview discussion.

Pilot tests of early interviews showed they took too long to complete, therefore some questions were replaced with closed questions with multiple-choice tick boxes derived from the range of pilot test answers. Review of the audio logs highlighted questions that took the longest to answer and also highlighted questions where the participant was unsure of what was expected. These confusing questions were rephrased for clarity, while the time consuming questions were optimised based on post interview feedback about the interview.

In the interview each participant was required to identify three natural resource issues that they deemed particularly significant. Successive questions harvested details specifically relating to the primary purpose of each of the issues. Three issues was determined to be an optimal number; the pilot study showed that choosing a single natural resource issue was difficult (and prolonged), whilst choosing five natural resource issues was too many, as participants tended to nominate issues quickly with apparently little thought for their significance. Limiting the selection to just three caused the participants to pause for thought, but not for too long. Also, asking for the issues in no particular order significantly hastened the thought time. The survey evolved as a balance between ideal and achievable, given the time constraints of participants. The revised interviews could be completed within 30 minutes.

The closed questions were a mix of Likert scale (Benyon, 2010), yes/no and *tick all that appl*y pre-determined answers. The Likert scales all ranged from the most negative on the left to the most positive on the right. Likert scales are particularly designed to collect perceptions and are the most common method to elicit opinions (Benyon, 2010).

One restriction of closed questions is that they may miss an answer that a respondent wants to give (Oates, 2006). To allow for this condition, all closed questions in the questionnaire contained an optional freeform comments line to remove limitations on potential responses.

3.5.1.4 Analysis

The quantitative information gathered in stage one was analysed using Excel for closed questions having an empirical answer, such as a number or a Likert scale. All questions with ordinal or numeric responses were analysed in Excel. These questions were analysed only using basic summary statistics and graphs.

The qualitative data analysis (QDA) computer software package NVivo was used to analyse all quantitative questions. For example: interview question three requests three natural resource issues that the participant feels are significant to the environment. These issues were entered as parts i, ii and iii to the question. In this way there were three times as many natural resource issues as there are participants. However, parts i, ii and iii were all analysed as if they are the answer to the same question. Natural resource issues that have similar meaning were coded as equivalent. An independent natural resource expert verified this coding. The issues were ranked them in order of importance by their frequency.

At the end of the analysis all information directly related to each Natural Resource Issue was collated using searches within NVivo, then exported to a single Excel spreadsheet. This created a single page summary document containing the justification of the issue, comprehension gaps, real world examples and main cause and effect relationships for each significant natural resource issue.

3.5.2 Stage Two

This stage had 6 objectives:

1. identifying the emerging technology for use in the study,
2. identifying suitable components of interfaces used in the emerging technology,
3. trialling the above components with regards to improving understanding of natural resources, by assessing usability, engagement and interface use measures of TUI components in designs,
4. selecting a significant natural resource issue from stage one to use as the topic for a TUI application and
5. consultation with community groups to refine learning requirements, priorities and implementation methods for use in the design of the final application.

The first phase of stage two was to compare types of emerging interactive technologies suited to natural resource interactions, in order to select the most appropriate type of technology for the research. Emerging interactive technologies encompass Augmented Reality(AR), Virtual Reality(VR), Multi-touch(MT) and Tangible User Interfaces(TUI). The most suitable technology, for this purpose was identified from a comparative evaluation of past related projects from within each emerging technology type. This first task was undertaken as part of the literature review as it is the fundamental prerequisite that determines all subsequent design and planning. Hence it was undertaken as early as possible.

Section (sections 2.4.6 and 2.4.8) in the literature review indicate TUIs are potentially the most suitable system, therefore the designs of this study's user trials focus on TUI criteria.

The second phase of stage two was to investigate the components of tangible user interfaces - in natural resource contexts - likely to contribute to the overall success of the interface. Measures of success incorporate:

Interface perspective:

- engagement,
- intuitiveness,
- efficiency, and
- fun factor

Adult learning perspective:

- measures of improvement in understanding of natural resource issues (retention of facts and concepts) and
- motivation and inspiration to act upon the teachings.

A breakdown of the components of TUI comprises:

- objects:
  - determining which interface elements to represent as objects ,
  - object design (fidelity, emotive attachment, associated coupling of physical to digital (Kirk et al. 2009), 'physical properties of objects, such as colour, size, shape, weight, texture, as well as material properties such as pliability, hardness, etc' (Edge & Blackwell 2006, p. 380)),
  - function of objects and
  - how to use the object for interaction.

- all non-object interface elements,
- design and implementation of the interface and lastly,
- characteristics of the target audience.

The interface design must consider how natural resource issues may be represented in a multi-touch and tangible system where user interface controls are touch, gesture, or objects. Consequently this stage:

- identifies which HCI metaphors are suitable,
- identifies which objects/artifacts may represent natural resource features or actions and
- assesses object design properties and affordance in a natural resource context.

The evaluation process uses a series of qualitative user experience studies of different designs of physical objects, interface configurations and interactions between elements of the interface. The user studies assess for appropriateness, suitability, engagement and usability. A brief, quantitative and qualitative questionnaire was used to provide feedback. The detailed comments and observations from the questionnaire provide useful insight and precise explanations that aid in rectifying problems with the existing system. A suite of usability and engagement measures were developed so that the interactions could be compared via an assessment matrix. The information gathered in this section directly contributes to the final stage.

The third phase of stage two involved the design of the final TUI application, incorporating the results of consultation with community groups to refine learning requirements, priorities and implementation methods. However, prior to any design development, the natural resource issue to be used as the topic of the TUI for stage three had to be selected. This choice was based on the ranking of the issues from stage one. The top ranked issues were reviewed for suitability in a TUI, using the design rules from the first phase of stage two. This evaluation process was necessary because of potential critical limiting factors impeding implementation into a functional TUI. These critical limiting factors include (but are not limited to):

- lack of available data,
- difficulties with designing objects that represent natural resource data or functions and
- lack of interest by the general public.

Once a natural resource issue was selected that met these three criteria, the community engagement phase commenced. This process is discussed in more detail in Section 3.5.2.3 Industry and Community Group Involvement.

The major user experiment in this stage also answers the fundamental question of whether adults even want to use model objects on a touch table. Is it something they find appealing, or useful?

3.5.2.1 Suitable TUI Components to Encourage Adult Learning

This research defines a *TUI component* as:

> A feature of the design of the tangible interface that uniquely contributes to the system, examples include: an encapsulated method, object design guidelines, or a specific style of use.

Potentially suitable components and techniques were identified in the system design phase by literature review of empirical multi-touch TUI studies on adults, selecting the components deemed significant to adult learning by the original authors. However, little empirical research exists showing learning, uptake, user engagement, or use preferences for adult users of multi-touch tangible systems (Antle & Wise, 2013; Schneider et al., 2010). The majority of past research for tangible objects focuses on children (Marshall et al., 2003;Price et al, 2008; Zuckerman et al., 2005), so consideration was given to multi-touch TUI studies on children. All the ideas harvested from the studies on children were balanced against their fit to andragogical guidelines to ensure their potential suitability.

Several of these TUI components were grouped together for testing in a single user trial. This study provided an opportunity to test some design concepts and fundamental underlying principles that were critical to the final solution. This study was a scoping exercise to gauge the reception of the target audience to some of the novel concepts. In addition, it evaluated TUI against its closest emerging technology rival (touch tables) in a practical map-based explorative exercise. The within subjects design was deliberated planned for participants to use both systems, so they would be in a better position to compare them (Speelpenning et al. 2011).

The main study in this stage uses a within-subjects design to compare the preferences of participants while they use four sets of controls – two sets of six tangible objects and two sets of six touch buttons. The explorative study measured the application usage behaviour of adults by recording the use of interface elements (frequency of use, duration, order of use and repeat use) and then obtained the subjects perceptions of the experience via a post-exercise questionnaire. The study measures user preferences, perceived engagement, fit for purpose, usability and enjoyment. This information clarified the design preferences for an interface using both touch and objects, while providing input for the design and composition of future interface elements and control methods.

TUI components were investigated as part of a number of trial constructivist task initial designs. Gamification (Deterding et al. 2011) was deliberately not applied in the design of these tasks within this study. The design criteria desired the tasks be realistic and practical, with no scoring, or completion statistics.

All of the concepts utilised in the design were evaluated initially by pilot studies (Section 3.5.2.2) to refine their design (Sharp et al. 2011).

3.5.2.2 User Studies including Pilot Testing of Underlying Concepts

Pilot user studies are a valid method to evaluate sections of an interface, questionnaire, or a proposed research method (Sharp et al. 2011). Typically studies involve 3-5 subjects who review a section, either by freeform use or directed use, while using thinking aloud commentaries (Benyon, 2010). Their feedback is considered in revisions of the design of the section.

Pilot tests are a full test of a proposed system before it is deployed to a wide audience. Pilot tests were conducted for each public exercise, as well as to evaluate significant elements of the final interface design. According to Benyon (2010) pilot tests are useful because they highlight obvious flaws by providing feedback on the hardware, software, interface design and user questionnaires. In addition any results provide estimates of variability and an indication of expected p values (Sauro & Lewis 2012a; Sharp et al. 2011). Pilot tests provide an opportunity to perform the analysis procedure on realistic data – a task that detects likely problems with the process of conducting the analysis itself, as well as problems with suitability of the outcomes from the analysis for their intended purpose.

As pilot tests are a dry run of the formal full implementation they provide practice for the instructor. They aid with the timing of the entire experiment, including the format of the experiment. As Benyon (2010) notes 'task completion time is often much longer than expected and instructions may need clarification'. Pilot tests provide feedback of the suitability of the supervisor record sheets plus they are an opportunity to field test the questionnaires for clarity and completion time. 'It is always surprising how an apparently simple question can be misunderstood.' Benyon (2010, p.161).

Each public exercise was pilot tested and revised based upon feedback, before being deployed. The key elements within each exercise, such as the physical models, constructivist tasks and questionnaires were all user tested, often multiple times.

A pilot study validated the design, but not effectiveness for learning, which requires more than 30 people for evaluation (Guest et al., 2006). The full empirical user study was required because 'Most current work in the field still invokes high level theories to explain possible learning effects without empirical validation' (Antle 2012, p. 234).

3.5.2.3 Industry and Community Group Involvement

Industry and community groups with a clear focus on the chosen natural resource issue were consulted and participated in action research activities.

One justification to consult with community groups is because the process is known to 'produce knowledge grounded in local realities' (Herr & Anderson 2005, p.98), thereby providing the Domain Specific Context needed for the interface. Adult learning theory indicates that adults are likely to learn 'most effectively when they are presented in the context of application to real-life situations' (Knowles et al, 2005, p67). This process contributes to research, as noted by Antle (2012) who recognises application of domain specific context in spatial problem solving as a knowledge gap in hands-on tangible interaction research.

After consultation with the main industry body it was decided that at least one community group was needed from each natural resource region in Tasmania (North, South and North West).

The community groups provided insight into the most practical and useful aspects of the interface, along with ways to present the natural resource information in a way that is realistic, yet engaging. Their guidance streamlined and pinpointed what was truly important from their perspective as active participants in the natural resource issue. This information may differ from the industry perspective, but is a subset of broader industry recommendations.

3.5.2.4 Participants for Stage Two

There are two styles of participants for this stage:

1. general user trials and
2. members of community groups.

Participants who are representative of the final target audience were selected for general user trials of the suitability, engagement and acceptance of TUIs. The target audience was adult members of the general public. There is no requirement for previous experience with touch devices, nor any knowledge of natural resources. These studies were conducted at the University of Tasmania. The major study operated on a University Open Day where members of the public participated. The experiment was conducted during slow periods of the day. The participants were uninterrupted because the experiment setup was in located in an isolated room. The open day was a valuable opportunity to use the interface with a wide variety of members of the target audience.

Members of community group were required to be adults. The selection of community groups used was guided by industry. These community groups were directly affected by the natural resources issue that is the topic of the final TUI application. Tasmania is topographically and socially diverse, hence the community groups were chosen as representative of the three natural resource management regions of Tasmania to ensure a balanced assessment of the chosen natural resource issue.

Activities with the community groups were conducted at the regular meeting site of each community group. All required equipment was transported to their site.

A minimum of 15 participants was required for both general user trials and of members of community groups as this is the smallest acceptable sample for qualitative analysis (Guest et al., 2006). However a combined sample of 20-30 is preferred. This was achieved.

3.5.2.5 Assessment Methods - Questionnaire Design

The assessment for the pilot user studies was via thinking aloud commentaries, which were audio recorded then analysed for feedback. All questionnaires were assessed using two methods:

1. subjects provided feedback as they completed each question within the questionnaire and
2. subjects completed the questionnaire, then provided feedback highlighting ambiguous questions.

The main study in this stage (*Around the World*) uses a within-subjects design to compare the preferences of participants while they use four sets of controls – two sets of six tangible objects and two sets of six touch buttons. The explorative study measures the application usage behaviour of adults by recording the use of interface elements (frequency of use, duration, order of use and repeat use) and then obtains the subjects perceptions of the experience via a post-exercise questionnaire.

The study exercise was timed, broken down into the length of time spent using touch buttons and the length of time spent using objects. This time included any local exploration of the digital map. The sequence in which the each button or object was activated was recorded using a structured note taking approach. Finally, participants were questioned about the specific reason for their first choice of touch button and object. At the end of the exercise the participants were asked to complete a questionnaire of 15 questions.

The short questionnaire of closed and open questions was designed for completion within five minutes. Six of the fifteen questions are yes/no questions; while another three use check boxes for answer choices. The order of the yes/no responses was alternated, so that participants needed to read each question and think about the answer (Brooke, 1996;Sharp et al.,2011, p241).

Usability and engagement was measured using a matrix (Figure 15). The responses are subjective from each participant's perspective. This is a deliberate design because the purpose of this exercise was to determine preferences between the available choices.

Q4 Please score each set of objects and buttons using a scale of 1-5 (1 being poor and 5 excellent) for all attributes in the table below:

	Ease of use	Fit for Purpose	Enjoyment	Level of Engagement
Text Objects				
Model Objects				
Text Buttons				
Image Buttons				
Location Dice				

Figure 15: Usability matrix in the user response questionnaire for the *Around the World* exercise.

This information clarifies the design preferences for an interface using both touch and objects, while providing input for the design and composition of future interface elements and control methods.

3.5.2.6 Analysis

The pilot user studies were analysed by reviewing the audio recordings of the user sessions, then salient elements were extracted and collated. All responses were considered, however repeated recommendations received greater consideration.

The analysis of the main public *Around the World* study calculated means, standard deviations and a Chi-square test. The Chi-square test is appropriate because it is designed to compare observed data with expected results (Sokal & Rohlf 1995).

The aim of the *Around the World* exercise is demonstrated by two hypotheses:

- Hypothesis 1: No object/button is chosen first more often than any other.
- Hypothesis 2: Each object/button is chosen as often as every other object/button.

Hypothesis 1 expects that every object is selected first an equal number of times, thus the expected frequency is calculated by dividing the number of participants by the number of objects. Hypothesis 2 expects that each object is chosen as often as every other, so the expected frequency is calculated by dividing the total number of times objects were selected by the number of objects available.

3.5.3 Stage Three

The final stage was the general public evaluation of the Natural Resources Tangible User Interface. The outcomes answered the research question: *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

The Tangible User Interface applied outcomes from the previous stages – incorporating the interaction, design and representation evaluations from stage two, to meet the needs of understanding natural resource issues outlined in stage one. The system was designed so the user sees the dynamic influences that natural resources have on one another. Tangible model objects control elements of these scenarios. The system design was optimised so that the interface elements appeal to different types of adult learners in an effort to maximise its engagement to the broadest possible range of people. The development of the interface was an evolutionary process based upon a user centred design methodology (Preece et al. 2011). This process allowed iterations to be tested, eliminating dead ends, while at the same time identifying the elements that worked effectively. User centred design methodology guided the design, functions, interactions and visualisations of the TUI within the boundary of the natural resource goal.

The interface was designed to incorporate a series of scenarios about a specific instance of a *dynamic of natural resources* determined from the information gathered in stage one (Section 4.3). These scenarios were used as working examples to demonstrate natural resource concepts and as practical exercises for participants to demonstrate their understanding.

This research follows a similar format as other TUI comparative evaluations in the following peer reviewed papers (Cuendet et al. 2012; Price & Falco 2011a; Schneider, Jermann & Zufferey 2010; Speelpenning et al. 2011; Terrenghi et al. 2007):

1. the TUI is compared to a non-tangible system where both techniques have the same functionality and
2. the subjects are divided into two groups where each one uses only one system, starting with a pre-test before using either system, then finishing with a post-

test. Schneider et al, (2013) uses a within subjects variation of a cross over experiment, where each group uses one system first, undertakes an interim test, then swaps over, taking a post test at the end.

The specific instance of a *dynamic of natural resources* was chosen during stage two as *Preparing for Bushfire*. The justification for the selection is available in Section 4.3. The following is the specific experimental procedure as it applies to *Preparing for Bushfire.*

The full user study applied a within subjects method to directly compare the *Preparing for Bushfire* TUI to the closest traditionally available method – instructor lead examples with Static Maps (Section 4.10). The advantage of using a within subjects design is all individuals and groups use both systems, therefore they are in a position to compare the two systems (Sauro & Lewis 2012b). It also eliminates potential imbalance from user personalities and group dynamics, as these user effects impact on both systems rather than just one (Speelpenning et al. 2011).

The detailed implementation procedure for the exercise is presented in Chapter 5: Experiment .

Comprehension metrics and questionnaire results, determine if and the degree to which, using map-based constructivist learning techniques encourages understanding of natural resources. The analysis of the metrics and questionnaire responses is discussed in 3.5.3.5 Analysis.

3.5.3.1 General Public Implementation of Natural Resource Tangible User Interface

In order to maximise the expose to the general public, the exercise was deployed to the main regional library and the city museum, as these locations were perceived as popular commonly used public sites. Furthermore, visitors to these sites were thought likely to both be adults and have spare time. The exercise was promoted to the general public by ABC radio interviews broadcast in primetime discussing the project, via flyers, word of mouth and via signage inside and outside the library.

The exercise uses a within subjects structure as outlined in Figure 16.

As participants arrive, they are presented with an Information sheet describing the experiment, along with a consent form explaining the OH&S issues and conditions of use of their results. Only participants who sign the consent form participant in the exercise.

Participants may undertake the session as individuals or as a group. The most common groups are couples who want to work together.

All participants complete a pre-test, which measures their current level of knowledge of the scenario topi to create a baseline. After which, they watched a 4min 30sec official *Preparing your house for bushfire* training video.

The participants are then separated into two groups, where each participant is placed into a group, according to a pre-prepared random stratified list in Excel. One group starts with existing methods, while the other group starts with the tangible interface. Then, all participants are tested with a written and practical test to measure their knowledge of the scenario subject domain at this point. The level of comprehension is measured by quantitative methods to test recall of facts and application of theory by active processes (Fink, 2003). The groups swap over to the other system where they complete some worked examples, followed by another written and practical test.

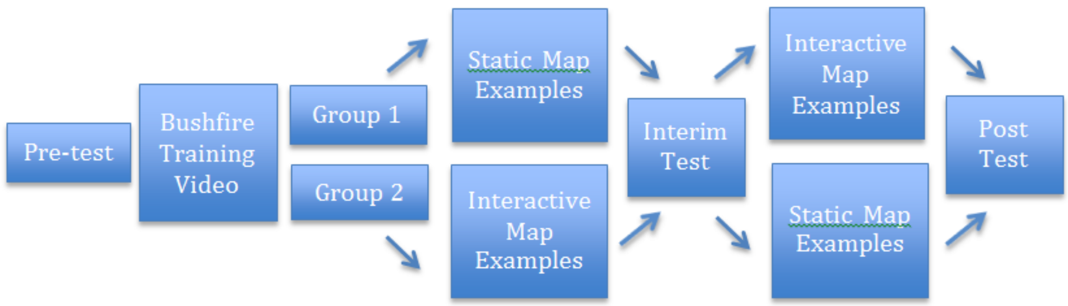


Figure 16: The within subjects design for the evaluation. All participants complete a pre-test, then watch the Bushfire Training Video. Participants split into groups. One group use Static Map examples followed by the interim test, then they swap to use the tangible Interactive Map examples followed by the post-test. Group two follow a similar format but use tangible Interactive Map examples first followed, interim test, Static Map examples, finishing with the post-test.

At the end of the exercise participants complete a detailed review questionnaire, described in Section 5.3 The Design of the Response Questionnaire about their experience. The questionnaire includes asking questions that provide evidence of any existence of indicators for learning (Knowles et al. 2005). Similar questions and analytical measures occur in peer reviewed constructivist comparisons (Ryan & Deci 2000; Zuckerman & Gal-Oz 2013).

Post processing coding the audio recordings of the user comments from the session quantifies the depth of understanding of underlying concepts, plus identified indicators for learning such as inspiration, engagement, memory triggers and occurrence of flow (Ryan & Deci 2000).

3.5.3.2 Pilot Test of Full System

The exercise in full was pilot tested by seven adults in two batches, prior to implementation. The first three testers were deliberately selected because they were adult academic staff, or post graduate students, familiar with academic research processes. The remainder were chosen because they had no knowledge of the project and were unfamiliar with academic research processes. All pilot testers were adults.

Changes were implemented to the exercise based on feedback by the first group of three academic testers. The revised exercise was subsequently evaluated as one group of two and two lone individuals.

3.5.3.3 Participants for Stage 3

Participants who are representative of the final target audience were selected for general user trials of the suitability, engagement and acceptance of TUIs. The target audience was adult members of the general public. There was no requirement for previous experience with touch devices, nor any knowledge of natural resources. These studies were conducted at the University of Tasmania.

The exercise required 64 participants for an even distribution amongst the comparable options while being sufficient in sample size for the quantitative analysis (Sauro & Lewis 2012) and for qualitative analysis (Guest et al., 2006).

3.5.3.4 Assessment Methods

The assessment in this stage used metrics from observation, system logs, practical tests, and questionnaires.

The interface was started anew for each new session with an individual or group of participants. New logfiles were generated with a filename reference specific for the starting date and time. These logfiles were matched to the session for later analysis.

The log files recorded position and time for all touches made on the table, whether deliberate or accidental. Touches included:

- finger touches,
- finger drag,
- finger removal,
- object placement touch,
- object movement,
- object removal,
- tagged object placement,
- tagged object movement, and
- tagged object removal.

Significant touch actions were recorded on the supervisor sheet for each session as a safeguard. These actions include all use of interface objects, and finger touch map navigation.

Each participant completed three tests (pre-test, interim test and post-test) outlined in order below. All three tests were of a similar format. The first three questions tested factual recall, while the second set of questions constituted practical exercises of three increasingly more difficult scenarios. All tests, exercises and the review questionnaire are explained in detail in Section 4.9 Design of Map-based Constructivist Exercises using Tangible Objects and Section 5.3 The Design of the Response Questionnaire.

The pre-test exists to establish a baseline for the ‘Preparing for Bushfire’ level of understanding of participants prior to the experiment session. The short test was designed to complete within 5 minutes. The first three questions were answered on paper, after which the participant was shown three photos of residential properties taken from NSW Bushfire Education. They were asked questions about their current state of bushfire preparedness as well as their recommendations for mitigating actions. Their verbal responses were compared to a concealed list of answers, and marked accordingly receiving one mark for each correct response. The list of answers is shown in Q12 observed in Figure 17.

The interim test and post-tests were identical in format and style of operation to the pre-test (Figure 18). The only difference was that the practical component differed from the pre-test in the way in which the properties were presented to participants. The properties were displayed on the Interactive Table as an aerial photo, overlaid with contours, property boundaries, and the recommended defensible zones, a reduced fuel zone around a house acting as a buffer against bushfire (Figure 38). The properties were presented in two forms: static and interactive. The property information was displayed as a static image when presented in static map form. However, tangible model interface objects (house, chainsaw, and a rake) were included for the interactive form. When used, the model objects displayed visual effects on the table signifying their real world effects they represent. Furthermore the property information map is navigable via pan and zoom, meaning the participant was able to move around the property viewing the neighbours, or zooming to see a regional view.

PRE-TEST

Start Time: ___________

Q11 What is the greatest danger to the property?

	1		2		3
Bush behind the house	☐	Surrounding Bush	☐	Surrounding Veg & close houses	☐

Q12 What actions do you recommend to prepare this property for bushfire?

	1	2	3
None, it looks well prepared	☐	☐	☐
Selectively clear Bush around the house within limits	☐	☐	☐
Rake leaves and bark	☐	☐	☐
Ember proof their home	☐	☐	☐
Add Water Tank/Dam	☐	☐	☐
Move Woodpile away from house	☐	☐	☐
Work with neighbours			☐
Improve road access to the house	☐	☐	☐
Make a bushfire plan to leave	☐	☐	☐
Restrictions may exist that limit possible changes			☐
Other	.....	.....	.....

Q13 In a severe bushfire event – would you Stay or Leave if you lived here?

	1	2	3
Stay	☐	☐	☐
Leave	☐	☐	☐
Depends on the circumstance – then justifies their answer	☐	☐	☐

End Time: _____________

Figure 17: The practical component section of the test above shows the expected responses. The participants did not see this page, as it was used only by the investigator during the session.

Participants were required to answer the same questions of the scenarios as in the pre-test, and were assessed similarly. Their verbal responses were recorded and compared to the same set of concealed answers, and marked accordingly; refer to Q12 in Figure 17.

In the interactive case the markings made by the rake and chainsaw aided in presenting the answer, as the objects alter the property map information to show changes.

All scenarios were derived from consultation with community groups in order to represent real world scenarios. In fact, they are all existing properties in Tasmania. All tests and scenarios were reviewed and approved by Tasmanian Fire Education Officers.

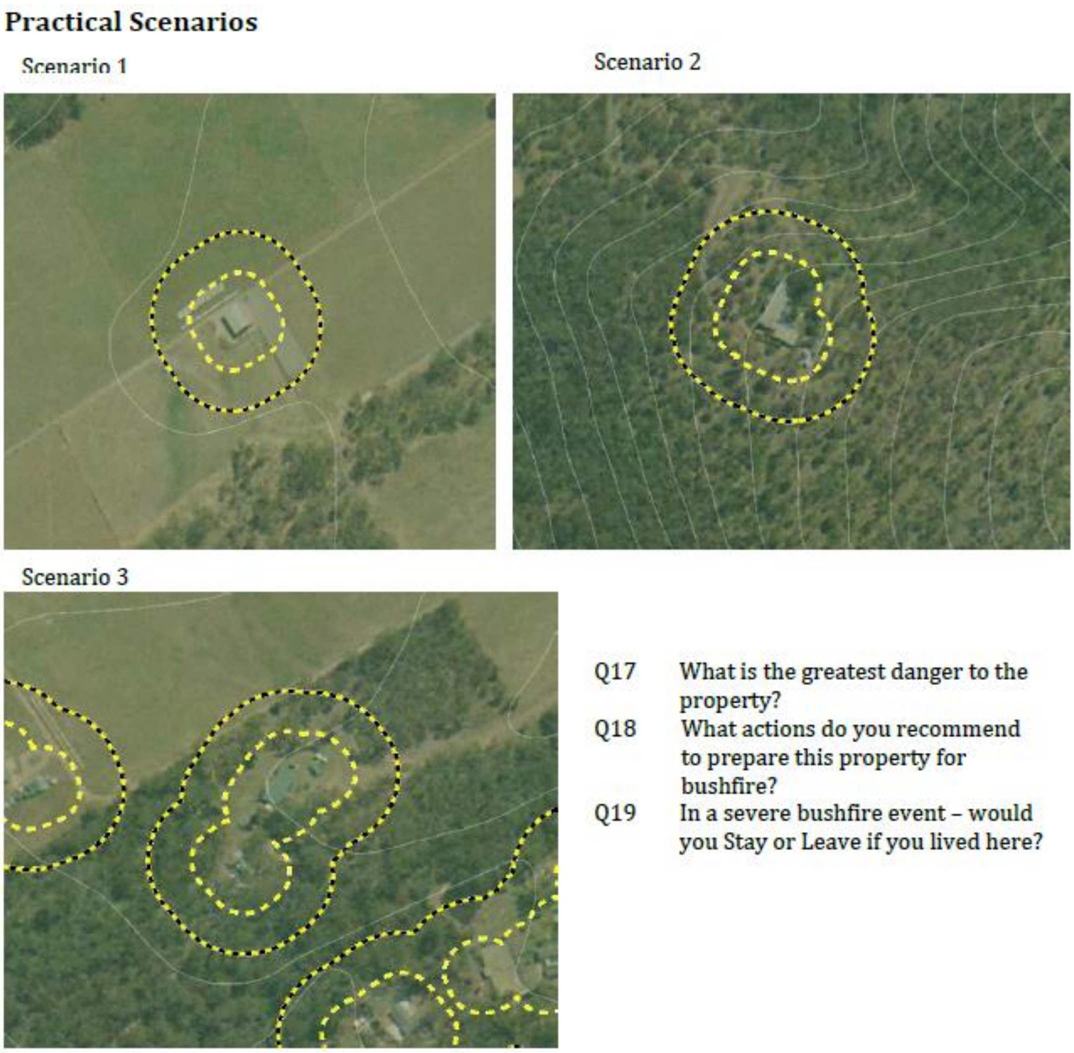


Figure 18: These practical scenarios are presented in the interim and post-test. The participants must answer Q17, Q18, and Q19 in relation to each of the scenarios.

The review questionnaire was presented to the participants after the post-test. It consists of 31 questions and takes between 3-10 minutes to complete. The questions focus on the experience as a whole, but are broken down into groups of questions.

The first group were focused upon the participants' perception of their learning experience. The first three questions ask yes/may be/no direct questions about the learning goals, and whether the participants' that felt they actually learnt from the experience. The last question in this group is a table listing all the aspects of the experience including the test questions, the touch table, the Interactive Map, etc. The participants were asked to rate how each aspect of the experience contributed to their understanding using a five point scale from *Not at all* to *Essential*.

The next group of questions are closed questions focusing upon aspects of interface design, and collaboration.

The third group of nine questions are concerned with engagement. The first three questions are direct questions about engagement of features of the interface using a five point scale. The next group of six questions are related to aspects of intense engagement called 'Flow' (Csíkszentmihály 1997). This is discussed in greater detail in the next chapter, the Likert questions include playfulness (Schneider, Jermann & Zufferey 2010), attention focus (Novak et al. 2000), and cognitive enjoyment (Zuckerman & Gal-Oz 2013). A combination of positively and negatively phrased was used, so that the participant would need to focus upon each question and think about the answer (Sharp et al. 2011).

The last group of questions focus on the overall design. One question asks for the most memorable aspect as an open ended question. An open question is the most appropriate for this style of reflection question as it provides flexibility for the response in their own words (Benyon, 2010; Price et al., 2003). The final question if a free form catchall question where the participant had the opportunity to provide any additional feedback they felt may be relevant.

The results of the user evaluation of stage three were intended to answer the final research question, as well as the overall research question.

3.5.3.5 Analysis

The analysis focused upon assessing the contribution of the interface towards *encourages understanding of natural resources* and how this is affected by *a tangible multi-touch table interface using map-based constructivist learning techniques*.

In the within subjects, structure, dependent variable is the style of the interface: Static Map or TUI Interactive Map.

The *encourages understanding of natural resource* component was assessed similarly to TUI studies of (Antle, 2012; Marshall et al. 2010; Streng et al. 2009) by measuring the change in the scores from the pre-test through the interim test to the post test. A higher score in the post-test indicates improvement in understanding and thus a learning gain (Howison et al, 2011).

The existence of learning is quantified by a paired-t test shown in results in (Section 6.6 Test for Presence of Learning). A paired t-test measures the difference between similarly measured outcomes caused by two different conditions (Quinn & Keough, 2002). The null hypothesis states there is no difference between the two, so fails if the test shows a significant difference, since this would mean that one method is better than another (Quinn & Keough, 2002; Sauro & Lewis, 2012). Paired t-tests are similarly used in the tangible experiment of Kraaijenbrink et al. (2009) to measure enjoyment and success.

The learning gain may be caused by multiple factors, therefore the analysis must show evidence of the contribution from a tangible multi-touch table interface using map-based constructivist learning techniques. This breaks down into two potentially contributing parts:

1. a tangible multi-touch table interface and from
2. using map-based constructivist learning techniques.

The contribution from *a tangible multi-touch table interface* was determined by a paired t-test of the test scores. In addition, comparison of performance between the static and interactive sessions was available using paired-t test results.

However, it is possible that test scores were influenced by the order of worked examples or of the tests. As mentioned in General Public Implementation of Natural Resource Tangible User Interface (Section 55.2.1), participants were assigned to eight different sequences. Each sequence is a specific order of worked examples, practical tests and whether static or interactive. An equal number of participants undertook each sequence to avoid bias.

The test for undue influence is to check that the sequence groups are equivalent. The standard method is to compare the means of the sequence groups (Quinn & Keough, 2002; Sauro & Lewis, 2012). Quinn & Keough, (2002, p200) recommend Tukey's honestly significantly differenced or Tukey's HSD test as 'a reliable test which compares each group mean with every other group mean in a pairwise manner'. Tukey's HSD is employed by (Javed et al., 2011) for their tangible tabletop occlusion assessment to compare a range of techniques. Group pairs with significantly different means represent techniques that have significantly different results. It means if the groups use the same interface (static or interactive) then the order of the worked examples or tests is significant and has an effect on the results.

The contribution from *using map-based constructivist learning techniques* was determined by both qualitative and quantitative assessment.

The qualitative analysis consists of coding of verbal responses for the practical test questions, coding of qualitative comments from the review questionnaire, along with the associated audio recording from the session. The coding from the audio recording used NVIVO, while the verbal responses to questions were coded during the exercise using an available list of acceptable responses. The quantitative assessment was made by statistical analysis.

The *map-based constructivist learning techniques* in the study were interactive scenarios of real world properties. The techniques were:

- worked examples using tangible model objects,
- practical exercises using tangible model objects in tests and
- the overall process of worked examples combined with practical test exercises.

Within these techniques HCI design features of the tangible objects contribute to their success or failure e.g. affordance, form factor and suitability.

Tangible model objects are integral to the worked examples and practical exercises. The contribution of the tangible objects was analysed for both frequence of use and for the overall length of time in which objects are used. In the former the analysis used a linear regression test, while the latter used a multiple regression model with factors of time and frequency.

The linear regression test was performed because the frequency of use of objects is hypothesised to directly contribute to a scalar value (Quinn & Keough, 2002), in this case being an improved test score. An improved test score indicated a learning gain. Linear regression is similarly used by (Cuendet et al., 2012) for their tangibles vs virtual empirical study.

Time is an important factor because *time on task* may influence test score and therefore learning gain (Price & Falco, 2011). Although Streng et al. (2009, p. 11) make the point that longer times may be indicative of cognitive difficulty, Antle & Wise (2013) note that time spent on constructivist tasks allows time for reflection or exploration (Antle et al. 2009) which are precursors for learning.

The time taken for constructivist tasks includes:

- Length of time spent using each individual interface model,
- Time spent on each exercise task,
- Time spent in total in:
    - the Worked Examples and
    - the Practical Exercises and lastly
- Combined overall time spent on constructivist tasks/techniques.

A linear regression test is used to evaluate the relationship between time and learning gain and time and test score, for both the interim test and the post-test.

The multiple regression model with factors of *frequency of object use* and *time spent on constructivist tasks* was suitable because the predictor variables were continuous (Quinn & Keough, 2002). The multiple regression model calculated the contribution from each of the factors and the significance of all factors together. The seven model assumptions were be calculated and met prior to running the model (Quinn & Keough, 2002). The multiple regression model should initially include all the factors that potentially impact the test scores, not just frequency of object use and *time spent on constructivist tasks*, e.g. contribution from prior knowledge. These factors should be reviewed by their contribution to the test scores. Factors that are non-significant should be removed from the model and the model rerun with the remaining factors. The model must include object use and *time spent on constructivist tasks* because these factors are directly linked to the hypothesis. The model results will confirm or deny the premise.

Engagement is calculated from three individual questions which are each collated to report the median value. The group of six questions about intense engagement, called Flow, are grouped together to create a single value index. The index represents the value of the Flow. A similar Flow index was created in the empirical TUI study by Zuckerman & Gal-Oz (2013). A Cronbach Alpha must be created for the index as a measurement of internal consistency, to ensure the questions are balanced and fair. Landauer (1997) noted that the acceptable value for Cronbach Alpha varies upon the purpose of the index, however for 'evaluation measurement reliability in the range of 0.7 to 0.8 is acceptable'.

Some participants completed the exercise in groups compared with participants who undertook the exercise as individuals. Educational theory (Antle, Tanenbaum, et al., 2011; Rogers et al., 2009) predicts that those in groups perform better than individuals. An ANOVA of group means provided a suitable test to compare the test scores and learning gains of groups vs individuals (Quinn & Keough, 2002).

The table in question 29 regarding *Perceived Contribution to Understanding from Features of the Interface* was presented by showing the distribution of the Likert responses highlighting the Median.

The remainder of the questions on the review questionnaire was evaluated on a case by case basis. Questions with Likert Scales were reported with the Median and standard deviation (sd)(Sharp et al., 2011).

3.6 Limitations

3.6.1 Participant Limitations – Characteristic Traits of the General Public

Experience from this research showed members of the general public are less open to direction than university student/academic subjects whom may have some familiarity with standard experiments. Members of the general public occasionally opted not to proceed in an exercise for their own reasons, whereas our experience of the students/academic participants showed that they eagerly follow directions. The behaviour of the general public is described as an impeding factor by Kildare (2010, p82) 'Live venue research may be derailed by the influences beyond the control of the researcher.' Consequently it was important for the interface to incorporate characteristics to appeal to and engage the general public.

3.7 Summary

This chapter has presented comprehensive justification for the research design. The methodology draws on well-established methods and statistical tests applied in similar circumstances in peer reviewed publications.

The within subjects design is founded on similarly structured studies of (Schneider et al. 2013; Tuddenham & Kirk 2010). The presence of learning was evaluated by paired t-test (Quinn & Keough, 2002) similar to the tangible experiment of Kraaijenbrink et al. (2009). Meanwhile, the learning gain was assessed similarly to TUI studies of (Antle, 2012; Marshall et al. 2010; Streng et al. 2009) by measuring the change in the scores from the pre-test through the interim test to the post test.

The initial stages similarly used well founded methods. The first stage used a semi-structured interview of open and closed questions for natural resource experts. The questionnaire made some use of Likert scales as they are specifically designed to collect perceptions and are the most common method to elicit opinions (Benyon, 2010). In the second stage, the analysis of the main public exercise used a Chi-square test. The Chi-square test is appropriate because it is designed to compare observed data with expected results (Sokal & Rohlf 1995).

Chapter 4: **System Design and Development**

'There is nothing like looking, if you want to find something. You certainly usually find something, if you look, but it is not always quite the something you were after.'
— J.R.R. Tolkien, The Lords Of The Rings

4.1 Introduction

Following on from the research methods which provided the overview, this chapter presents specific details of the design of the tangible interface system.

This chapter will explain the comprehensive design of both the custom tangible touch table interface and the map-based constructivist tasks.

The chapter starts by presenting the contributing outcomes from stages one and two. (The detailed results and discussion for each are available in Appendix 1). The completion of stage one provides the opportunity for the selection of the application topic. The argument for *Preparing for Bushfire* as an appropriate choice for a Tasmanian natural resource issue is presented. Immediately followed by the contributions and recommendations from the participatory involvement with three bushfire community groups and industry.

The discussion changes to design considerations for the tangible interface, starting by revealing a table of the components of TUI selected from empirical studies of adults. This continues with guidelines for tangible object design, collaboration and physical-digital coupling. The preliminary design of the tangible touch table interface is pilot tested along with the preliminary experiment design at Kingston Shopping Centre. This experience is examined highlighting lessons learned, prompting a redesign of the experiment. These lessons, along with the tangible design guidelines and feedback from the community groups, are applied to the *Preparing for Bushfire* interface design which is then shown and explained. An improved set of map-based constructivist exercises are developed, described and justified. These replace the preliminary tasks within the main system.

4.2 Contribution to the Research from Stages One

Stages One and Two were completed as per the Research Design (Sections 3.5.1 and 3.5.2). Results and discussion from these stages are detailed in Appendix 1.

The outcomes from these two stages directly contributed to the design of the last stage for the development of the tangible interface and experiment implementation. These outcomes includes a series of pilot studies, described in Appendix 1, which are about developing and understanding of people's interaction with map-based applications and tangible object use preferences.

The outcomes that were learnt from this experience that advanced the research design are the following:

1. The responses from the interviews provided the most desirable options for application topics (Table 1) for the final TUI system. The cause and effect, key concepts, misunderstood concepts, interconnected relationships and real world problems, formed sufficient information to determine how much and what, should be understood to meet an adequate need as depicted by natural resource experts.

Table 1: Main natural resource issues

Issue	Count
Water Quality and Quantity	11
Exotic Flora and Fauna – Weeds and animal pests	9
Loss of Habitat	8
Abandonment of Private Forestry	6
Urban Sprawl	5
Soil Erosion	5
Mining in the Tarkine Wilderness	3
Climate Change	2
Lack of sharing of monitoring & evaluation flora/fauna/land data from single scope projects	2

2. Selection of the choice of application topic of *Preparing for Bushfire* (Section 4.3)

3. Adult users perceive hi-fidelity model interface objects to be both the most enjoyable and the most engaging compared with traditional touch buttons

and low-fidelity (yet low cognitive load) interface objects (Appendix 1 Stage Two Results and Discussion).

4. General public adults prefer interface objects over touch buttons when objects represent the primary focus point objects (Appendix 1 Stage Two Results and Discussion).

The following outcomes justified the underlying premise and fundamental interface design choices:

1. 80% of the natural resource experts believe that the general community has a poor understanding of the interconnectedness of natural resources. Furthermore, 86% agree that a lack of understanding of interconnectedness of natural resources adversely impacts the environment. These figures support the underlying premise, that general public have a poor understanding of the flow on effects of natural resource issues (Section 3.2).

2. The recommendation for preferred tools and techniques is one that is: educational, interactive, and uses physical tools to show visual information.

3. Adults engaged with and enjoyed the map metaphor, successfully applying spatial reasoning with explorative tasks (X2 (3, N = 19) = 56.62, p < .01). This outcome justifies the potential use of these components of TUI for the final design.

4.3 Justification for Choice of Application Topic of Preparing for Bushfire

Bushfire is a visible example of a complex dynamic of natural resources because bushfire occurs as a consequence of a change in one or more natural resources. Bushfire Risk Likelihood is determined by the composition of vegetation, wind, topography, road access, evaporation, rainfall, temperature, available fuel load, soil wetness and layout of the surrounding community.

The choice of *Preparing for Bushfire* as the application for the research considers the opinion of natural resource experts from stage one of the research that:

- many natural resource issues are considered “pie in the sky”, being too far removed from the individual and
- the general public tend to focus on problems close to home - ones that directly impact their immediate circumstances – such as family woes and financial shortfalls.

Bushfire preparedness for peri-urban (and rural) residents is an example of a natural resource issue (humans impact the environment negatively) that has consequences that directly affect the individual. Residents run the risk of losing their house, all their belongings and possibly their life. The targeted audience potentially have high emotive attachment. Therefore it is an ideal topic to use because it should appeal to residents and potential residents, because of the direct effects and high risk.

Yet despite the risk, few residents regularly prepare for the bushfire season (Mackie et al. 2013; Boylan et al. 2013). To partly address this issue the Bushfire CRC funded a PhD Research project with the University of Tasmania to explore reasons why communities are hesitant to prepare their homes for bushfire. The research titled *Promoting Community Bushfire Preparedness: Bridging the Theory – Practice Divide* (Fransden, 2012) was completed in 2012 by Mai Frandsen. The abstract describes the research as:

> a model developed to predict adoption of bushfire preparedness measures and to subsequently apply the motivational factors found in this model to develop more effective and sustainable community bushfire preparedness initiatives.(Frandsen, 2012,pV).

The research from the PhD prompted the creation of the Bushfire Ready Neighborhoods Pilot program within the Tasmanian State Fire Service.

The Australian fire service note that recent bushfire fires seem to be increasing in ferocity and intensity. Tasmanian fire services are stretched because of a lack of funding and human resources. Tasmanian Fire Service (TFS) services are forced to reconsider priorities to be more efficient to maximise their effectiveness. TFS now require rural residents to take bushfire preventative steps and then submit proof to TFS in order to receive higher level of support in the event of bushfire.

Climate futures of Tasmania project (Grose et al., 2010, p4) predict hot dry climate forecasts for summer which heightens residents' perceived need with more to gain by *Preparing for Bushfire*, but still most do not prepare (Mackie et al. 2013; Boylan et al. 2013). Only approximately 9% have completed a written plan (Mackie et al., 2013).

The Tasmanian Fire Service believes bushfire is a significant risk for peri-urban residents on the fringe of Urban Sprawl (Discussion with TFS education staff). TFS believe the lack of uptake of bushfire preparation by residents is so significant that they are creating a new community education team of 4 officers to counter the problem.

The 2012 Survey of Natural Resource Issues (Stage One) identified the issue of bushfire risk for Urban Sprawl as a significant issue. Furthermore *Preparing for Bushfire* links to 6 of the main issues (Table 1) identified by the 2012 Natural Resource Issue Survey:

1. Abandonment of Private Forestry (Lack of management is a bushfire risk)
2. Loss of Habitat,
3. Climate Change (Increases the risk of bushfire higher temperature, higher evaporation),
4. Exotic Fauna (Weeds are the first vegetation to return after a bushfire),
5. Water Quality and Quantity (Access to water for fighting fires) and
6. Urban Sprawl.

These linkages indicate the topic of *Preparing for Bushfire* is directly relevant as it flows on from the first stage of research.

Preliminary checks for the critical limiting factors mentioned in Section 3.2 indicate that for *Preparing for Bushfire* there is likely no:

- Lack of available data,
- Difficulties with designing objects that represent natural resource data or functions, or
- Lack of interest by the general public.

As pointed out by Knowles et al, (2005, p294) 'Adults are motivated to learn after they experience a need in their life situation.' *Preparing for Bushfire* meets the need as it may potentially save lives.

4.4 *Around the World* Exercise to Evaluate Fundamental Concepts

This exercise groups TUI components together for evaluation as part of a single user trial which further provided an opportunity to test some design concepts and fundamental underlying principles critical to the final solution.

The fundamental principles tested are:

1. Map Metaphor (Displaying map-based information on touch table) and
2. Objects for interaction with the interface,

It was important to know if adults accepted using objects to interact with the table and if they engaged with map-based information in the style envisioned for the final TUI system, because these features were critical to potential success of the final TUI.

The components incorporated from other TUI studies included:

1. Spatial Reasoning,
2. Explorative tasks (most basic constructivist task) and
3. Preliminary object design rules.

It is necessary to know how these perform with a general public audience. Mostly these components were evaluated in previous studies using students (a selection of such: Lucchi et al. 2010; Schneider et al. 2013;Terrenghi et al. 2007; Tuddenham & Kirk 2010; Zuckerman & Gal-Oz 2013), so they may have a different reception when used with the general public. In addition these components need to work together in the final system, so evaluating them working together at this point provides useful insight for the later design.

The user preferences were evaluated by testing the following hypothesis':

Hypothesis 1: no object/button is chosen first more often than any other.

Hypothesis 2: Each object/button is chosen as often as every other object/button

The study uses a within-subjects design to compare the preferences of participants while they use four sets of controls – two sets of six tangible objects (Figure 19) and two sets of six touch buttons (Figure 20). The study task uses each interface set (touch buttons and tangible objects) to navigate to six unique locations around the globe that are displayed on the table using online aerial images from Bing Maps. The exercise was conducted on the University Open Day. The within subjects design was deliberated planned for participants to use both systems, so they would be in a better position to compare them (Speelpenning et al. 2011).

The two tangible object sets are:

1. Ideal objects – High fidelity model objects with clear representative purpose and
2. Signposts with text only.

The signposts with test objects are the simplest, cheapest and quickest tangible markers to create, requiring little effort, as opposed to the ideal objects which took considerable time to make and source for suitability, size, fidelity, graspability, texture, etc. The comparison will determine if there is benefit from expending the resources to create ideal objects rather than basic objects. The decision to use signposts was born from inspiration from WWII Battle of Britain movies and because fidelity and abstractness has been empirically studied Heijboer & Van Den Hoven (2008), yet text signposts do not appear in empirical studies of TUI.

The experiment compares how participants use detailed model objects and objects with text to equivalent touch button sets. Models of well-known easily recognisable landmarks were chosen as the preferred tangible objects to represent locations around the world: the Eiffel Tower represents Paris, Sydney Opera House represents Sydney and a pyramid represents Giza. However, not all locations have a single well-known landmark, as is the case for Las Vegas that we choose to represent by a display of dice and cards to characterise gambling - a pastime well associated with Las Vegas. Similarly, a group of elephants was selected to represent Africa. Lastly a foam house stamped with the university logo that was distributed plentifully during the University Open Day was used to represent the location of the University, refer Figure 68. These objects deliberately contain a variety of textures. The Eiffel Tower is made of metal just as the actual tower is made of metal, similarly the Giza Pyramid is made of an earthen substance to simulate the actual construction material of the real Pyramid.

Figure 19: The sets of tangible objects for the *Around the World* exercise.

This best choice set of objects is still susceptible to possible misinterpretation, whereas a tangible object set that only shows the name of the each location, similar to a signpost, is very clear, requiring minimal cognitive load.

Similarly to the object sets, two touch button sets were created - one consisting of images of well-known landmarks and the other consisting of just the name of the location containing the landmark as simple text (Figure 20). The objects were all of comparable size, while the buttons all had both the same size and luminosity. The objects and buttons were grouped within their own set, but were randomly arranged in a line.

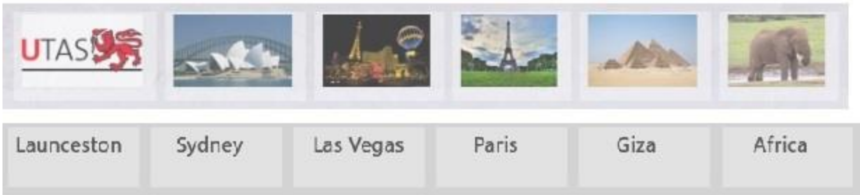


Figure 20: The 2 sets of interface buttons for the *Around the World* exercise

In order to reduce the novelty factor, each subject was allowed to use the touch table for five minutes prior to the experiment. They were able to play with a number of simple applications, such as on-screen painting with an actual paintbrush. This short play period introduced subjects to all the features of multi-touch as well as the idea of using a tangible object (paintbrush shown in Figure 11).

The experiment protocol was explorative and freeform without time limit. There was no set goal besides exploring to satisfy curiosity. Subjects stopped using the system when they were satisfied with what they had seen. They were permitted to navigate to the locations using the touch buttons or objects and were able to explore the local region using panning and zooming. They moved to the next location of their choice when they were ready to do so. The subjects were not told they would be timed.

When an object or button was activated the display zoomed to the associated location. For example placing the Eiffel Tower model object upon the surface relocated the map view to the grounds around the Eiffel Tower as shown in Figure 21. Objects were activated by placing them anywhere on the surface, while buttons were activated by finger touch.

Every second participant started the exercise with touch buttons then switched to objects, whereas alternate participants started with objects then switched to touch buttons. If the participant started with touch buttons, then they were instructed to select and then use a touch button of their choice, then to continue to use other buttons in their own order of preference until they wanted to stop using the touch buttons. The participant subsequently switched from touch buttons to objects (or from objects to buttons if they started with objects) and then the process was repeated.

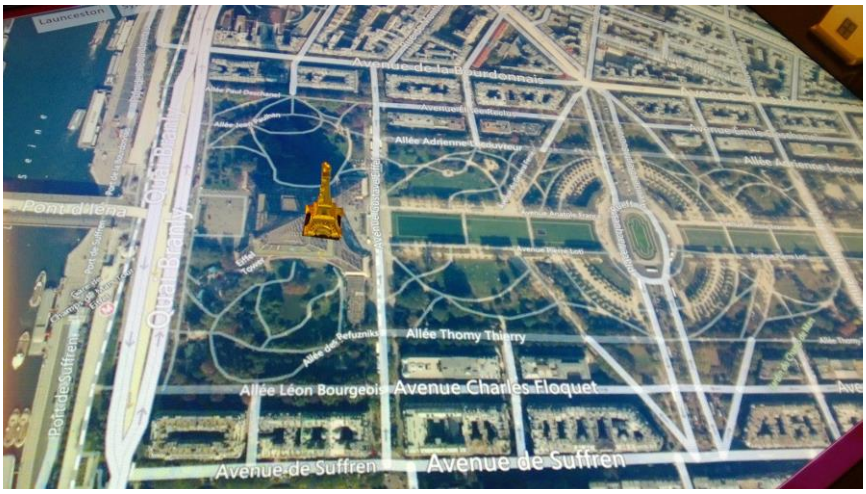


Figure 21: The model of the Eiffel Tower (gold) sitting on top of the digital display of its real world location in Paris

A structured note taking approach was used to record how participants interacted and collaborated with each other, when players started interacting, how they used the tools and how this changed over time. The post exercise questionnaire provided information about useability, suitability and preferences.

By observing the interaction behaviours of 20 participants, the 'Around the World' study investigates the appeal of two distinctly different styles of tangible objects compared with their finger touch equivalents. The explorative style study measures user preferences, perceived engagement, fit for purpose, usability, and enjoyment.

A pilot study of the exercise was conducted using three adults, from which all unanimous recommendations were applied. One such recommendation advised replacing model objects that were considered to be abstract. Consequently a round-based pyramid was replaced with a square-based pyramid, and the model of the Sydney Opera House was improved to be more realistic. The text buttons were moved from the bottom of the display to the top to avoid accidental activation.

The participants comprised 20 adults of the general public (10 males, and 10 females) aged between 18 and 55. Of these, 60% of the participants considered themselves to be very familiar with touch technology, although all had little or no prior experience of touch table interfaces.

The frequency of use of objects and touch buttons showed that the model objects were used more than twice as often, per participant and in total, as the next closest type (Figure 22). Model objects were used on average 5.68 times, while buttons with images were used 2.68 times.

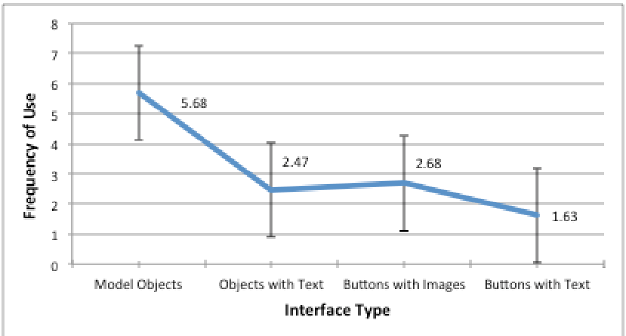


Figure 22: Frequency of use of interface elements showing one standard deviation as error bar

Chi Squared results of frequency of use shows model objects were chosen significantly more often than any other interface type X^2 (3, N = 19) = 56.62, p < .01. The breakdown within the object groups shows a significant difference in preference for model objects, X^2 (11, N = 19) = 25.84, p < .05 compared to objects with text. Similarly, the touch button usage shows a significant difference preference for touch buttons with images X^2 (11, N = 19) = 13.21, p < .05 compared to touch buttons with text.

For their first choice, the participants showed a statistically significant preference for the Las Vegas Model X^2 (11, N = 19) = 25.86, $p < .05$, and a statistically significant preference for the Sydney Image button X^2 (11, N = 19) = 12.83, $p < .05$. The most common reason (70%) given was “It appealed to me the most”.

The results indicated a clear preference for detailed model objects over other interface types. The qualitative comments support this preference indicating that models should have a strong representation to their associated location. Qualitative responses also suggested that objects with text, and touch buttons with text, provide a very clear message of purpose and action, requiring little cognitive load (as suspected).

Participants ranked their perception of ease of use, enjoyment and engagement with the interface types as shown in Table 2. All the interface types were considered to have equivalent ease of use and fit for purpose. The model objects were perceived to be both significantly more enjoyable, and significantly more engaging than any other type. This is reflected in the frequency of use in Table 2, and in the length of time spent using the interface types.

Table 2: Means of user perception using a 1-5 rating with 5 being best.

	Ease of Use	Fit for Purpose	Enjoyment	Engagement
Model Objects	4.56	4.39	4.72	4.72
Objects with Text	4.61	4.29	3.24	3.24
Buttons with Images	4.53	4.35	3.82	3.82
Buttons with Text	4.67	4.53	3.29	3.06

The tangible objects were used on average for 399 seconds (stdev=145 seconds) per participant (average=52seconds per object). Touch buttons were used on average for 192 seconds (stdev=98.9 seconds) per participant (average=50 seconds per button). More time was spent engaged with objects regardless of whether participants started with objects or buttons. Overall, the participants spent almost twice as long using objects than touch buttons because they used objects nearly twice as often. Typically higher times are indicative of user problems with an interface, however in our case the high enjoyment from Table 2 suggests the higher times occur because of engagement rather than interface design flaws.

The model objects were the consistent superior choice. Multiple design choices are made when selecting a tangible model object; most importantly it must have good representation for affordance, be useable and fit for purpose. Although an ideally representative model takes significant time to design and manufacture, our results show the effort is justified because they were more enjoyable, more engaging, and were used significantly more often than the alternatives.

4.5 Programming Environment

Software development on the PixelSense uses the Surface SDK 2.0 integrated with Microsoft Visual Studio 2010. The Surface SDK 2.0 is freely available for download from Microsoft and is supported with online documentation on the MSDN website. The SDK uses the C# language with the .NET 4.0 environment.

The "preparing for bushfire" interface is based upon WPF. It was created from Visual Studio WPF templates installed by Surface SDK 2.0. WPF was chosen because the API for the mapping information uses WPF – specifically it uses ArcGIS runtime for WPF – available for free download at http://resources.arcgis.com.

ArcGIS was chosen because it is the largest and most well-known of the Geographic Information Systems (GIS). Additionally the ArcGIS API operates using a .NET environment which makes it compatible with Surface SDK 2.0. Furthermore online tutorials exist for both the ArcGIS API and the Surface SDK.

4.5.1 Operational Logistics of the "preparing for bushfire" Interface

The interface is controlled by finger touches and object control. Objects are best tracked via the use of Microsoft Tags (Figure 1). The bushfire interface uses three objects: House, Chainsaw and Rake. The house and Chainsaw use Microsoft Tags, but the Rake is treated as a BLOB. Programmatically BLOBS are handled identically as finger touches, except they have a touch_id of BLOB.

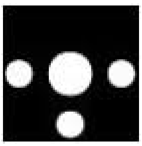


Figure 23: The PixelSense will *programmatically recognise any object that has a Microsoft Tag attached.*

The interface is defined using WPF, so it is created using XAML. Much of the interface was built using the toolbox to define the interface controls.

The map layers themselves were accessed online from the Tasmanian State Spatial Data repository called theLIST (https://www.thelist.tas.gov.au). The bushfire interface only uses three map layers : Statewide Orthophoto, 10m contours, and property. The format to load the maps is similar to the example for Statewide Orthophoto :

<esri:ArcGISImageServiceLayer ID="Background AirPhoto" x:Name="Orthophoto" Url="http://services.thelist.tas.gov.au/arcgis/rest/services/Basemaps/Orthophoto/ImageServer" />

4.6 Tangible Interface Design

This section describes characteristics of TUI that were the foundations of the design of the map-based tangible table interface used in this thesis and presented in Section 4.8.3.

4.6.1 Components of TUI

This section is part of stage two which is outlined in the Research Design chapter in Section 3.5.2. This represents a major milestone that significantly contributes to the design of the interface and the experiment design.

Existing TUI empirical studies with adult subjects were reviewed for application purpose, techniques employed, measures applied, target audience and participants. Techniques that were thought to contribute to the research purpose were collated (Table 3). Adult studies were separated from studies on children because children and adults learn in different ways (Knowles et al, 2005) and this study is only concerned with adults.

Table 3: Components of TUI from empirical studies.

Relevant Component of TUI Study	Empirical Study	Participants	Finding
Spatial reasoning	(Lucchi et al., 2010) (Cuendet et al., 2012)	n=40 Adult students n= 46 (16 year old male students)	TUI more effective than touch Reduced cognitive effort using TUI
Constructivist behaviour (exploration, collaboration, playfulness)	(Schneider et al., 2010)	n=28 Adult students	Greater learning gain from using TUI
Exploration (discovery learning)	(Tuddenham & Kirk 2010)	n=12 Adult students	TUI easiest to learn and most accurate to use.

	(Zuckerman & Gal-Oz 2013)	n=58 Adult students	No clear performance advantage, yet TUI preferred.
Collaboration with objects. Physical object replaces touch tool,	(Speelpenning et al. 2011)	n=45 Adult students	No real benefit from using object tools over touch, yet users liked using physical artefacts.
Representation	(Terrenghi et al., 2007)	n=12 Adults	Tangible outperformed multi-touch

The components of the prior TUI studies were utilised in the design process. A selection of the components was evaluated as a trial (Appendix 1) with adults for usability, fit for purpose and to evaluate how well they are accepted by general public adults.

4.6.2 Effective Physical – Digital Coupling

The objects in the *Around the World* exercise (Figure 19) were designed for high representation with multiple linkages to sensory stimuli – meaning they were both visually stimulating and haptically stimulating to a high degree. The Eiffel tower object was a highly detailed miniature metal model replica of the actual Eiffel tower. It is multi-sensory because it is visually detailed providing visual stimuli and being made of metal it has weight when it is moved providing haptic stimuli. The other mental stimuli are it is metal like the original, it is painted like the original and it is high detailed. These features combine to make this object easily recognisable for its representation. The Giza pyramid goes one step further as its construction material leaves a dusty residue on the fingers further enhancing the haptic feedback and stimulating the senses. User feedback demonstrated significant preference for aesthetic objects.

Similarly the objects designed for the *Preparing for Bushfire* interface have high level of detail, require actions similar to the real world objects they represent and show real time immediate visual response when used. The interface coupling was evolved through user testing into its final form.

4.6.3 Tangible Object Design Guidelines

The interface objects were designed with consideration of a number of guidelines from fundamental features of tangible objects incorporating physical characteristics and restrictions for replicability and application.

Heijboer & Van Den Hoven (2008, p.162) point out that the originators of TUI object design (Ishii & Ullmer 1997) state :

> there are four important characteristics of tangible interfaces:
>
> 1. The physical artifact is linked to the digital function.
> 2. The physical artifact allows the user to have free control over movement and interaction.
> 3. The representation of the physical artifact is linked to its function and
> 4. The physical state of the artifact shows the actions of the system.

These four design characteristics have been taken into account when creating the interface. The design also considered the overarching design goals:

- existing & available hardware,
- existing & available software including API/SDK,
- existing & available real world data from authorised source and
- apply in context.

Furthermore the design employed Natural User Interface design concepts so the target audience would use the emerging hardware technology seamlessly, because the application function combined with information presentation attracted and retained their attention focus, rather than the novelty of the technology. The interface design should naturally guide users' attention to what matters the most.

The interface objects itself must be carefully designed not to be overly aesthetic, because it becomes the focus of attention rather than the purpose of the interface. It was noted in pilot tests that highly detailed aesthetic objects were frequently handled more than required for their purpose. Sometimes the objects were removed from the interface to be examined in detail and commented upon for their high level of beauty. The focus upon the object appeared to change the focus of attention of thought of the user when too appealing. One potential solution is to design linkages from the object to the users to the interface, thereby coercing the user to want to use the object within the interface. This problem only occurred for first time users, rather than frequent or repeat users.

The following are the object design guidelines that were implemented in the tangible multi-touch table interface using map-based constructivist learning techniques, many of these were derived from a series of user tests:

a. The technology must not be perceived by the end user as gratuitous. It must be fit for purpose. The application design must incorporate techniques/mechanisms for using the emergent technology so that the take away message is the goal of the application rather than the novel emergent technology (Mancini et al. 2010).
b. Object choice must be appropriate and make use of the beneficial features of haptics/kinesthesis where possible (Kim & Dey 2010). For example to design multi-sensory features by incorporating texture or iconic colour.
c. To reduce cognitive load, objects should be models of everyday objects rather than abstract or unfamiliar designs (Costanza et al. 2010).
d. Aesthetics matter. High fidelity aesthetically appealing objects are preferred, unless they are so appealing users focus upon these to the exclusion of the interface.
e. The objects need to have an inherent linkage/coupling to the interface (Price 2008b) or to the user of the interface. For example using a model of the Eiffel Tower to move the map location to Paris appeals to those who have visited Paris. It brings forth memories – hopefully fond thoughts – thereby enhancing the appeal of the Eiffel Tower object.
f. Objects must be functional. They must be graspable (able to be moved/picked up with forefingers and thumb), usable by either hand (Fitzmaurice 1996). They must have a base large enough for a Microsoft tag id (Microsoft 2011).
g. Presently the general public of all ages seems to have a fascination with 3d printed objects. At the moment 3d printed models are well accepted. When 3d objects are used they do not need to be coloured, as observation shows that colour makes little difference to their acceptance. However tests by the author showed the standard white plastic behaves as a reflector of infra-red, thus causing false touches.
h. The manner how objects are utilised in the interface must be purposeful and relevent for their purpose. For example: Allow an object to be placed upon the surface in any orientation, unless there is a specific reason that orientation matters (Microsoft 2011).
i. Be flexible with the table detection and response to the objects, allow room for error, because general public adults are generally unfamiliar with tangible model objects.

j. Although not part of this study, it is the view of the author that 3d printed tangible interface objects are cheap enough that they may be gifted as a memoir of the experience, thus becoming a permanent memory prompt for later reflection.

The final complete list of recommended guidelines founded from the results of the full general public study are listed in Section 7.7 Answering the Research Question.

4.6.4 Design Considerations for a Collaborative Interface

The interface was designed for use with multiple simultaneous and collaborative users. All touch and object interactions within the interface may be performed by multiple users.

The underlying nature of the touch table allows simultaneous multiple users as noted by Xie et al. (2008, p. 191) 'One major advantage that has been identified with for tabletops is that they can support synchronous co-located collaboration.'

Although the touch table hardware already operates for multiple users, the interface has the opportunity with the design to value add to this ability. The interface benefits from a design which takes optimal advantage of collaborative desirables. Hence the interface objects are specifically designed as the focus of the interface therefore meeting the guidelines for TUI design outlined by (Antle & Wise 2013, p. 13):

> Implications for TUI design Guideline 10: creating configurations in which participants can monitor each other's activity and gaze can support the development of shared understandings (design of physical and digital objects). An important precursor to collaboration is shared attention; learners cannot meaningfully negotiate and develop common understandings if they are not attending to what each other are doing.

The interface objects share the attention for the task, prompting discussion. Speelpenning et al. (2011, p.5) note this may be simply caused as 'a physical artifact draws attention when a user picks it up from a tabletop and moves it in 3D space in front of their body.'

Incorporating the capacity to function collaboratively allows comparison of engagement between collaboration and individuals which is purposeful because Horn et al. (2011, p. 7) suggest in their empirical TUI tabletop study 'This suggests that for engagement, the type of interface might be less important than actively involving multiple participants.'. The research goal for this thesis relies upon engagement being formed from using the interface.

4.6.5 Novelty Avoidance

New technology has a novelty factor that encourages attention so improvements in interfaces are sometimes attributed to novelty rather than merit for better design (Ott & Luderschmidt 2012).

In order to reduce the novelty factor (Price & Falco 2011a) of tangible objects or touch tables, each subject was allowed to use the touch table for five minutes prior to the experiment. They were able to play with a number of simple applications, such as on-screen painting with an actual paintbrush (Section 2.6.5). This short play period introduced subjects to all the features of multi-touch as well as the idea of using a tangible object (the paintbrush shown in Figure 11).

The length and style of the session was based upon observations of hundreds of users from public demonstrations and University Open Days.

4.7 Action Research Experience

The initial concepts of the map-based natural resource TUI were presented to the TFS education as a possible aide to bushfire education on the 6th July 2013. The demonstration was presented using a ArcGIS project showing data layers for the state-wide Orthophoto, Vegetation maps, and Climate derivatives. These were demonstrated with verbal explanations of escape planning and visualisation of the local community. This concept design was accepted as plausible, so a *Preparing for Bushfire* specific interface was designed in consultation with TFS, based upon the educational needs of the Bushfire Ready Neighbourhoods Program http://www.bushfirereadyneighbourhoods.tas.gov.au

TFS agreed to pilot the system with community groups to establish usability and viability. The community groups would also provide their perspective on specifications for a tangible touch table system for use with the general public.

4.7.1 Participatory Research

Twenty years of project based work experience guided the inclusion of input from bushfire community groups because members of such groups know what they need to know and why they need to know it, although, they may not necessarily have the knowledge itself. They know what are the most important facts and concepts from their own perspective of living with bushfire risk. Usually these groups have experienced training/awareness seminars by Tasmania Fire Service (TFS) and know which sections of the training were relevant and which were not. They also know what was missing from the training that they want to know. External organisations offering education may not necessarily teach what community groups want to know.

The research design trials the system with the community groups in order to identify which elements of *Preparing for Bushfire* the community groups (people who live with the natural resource issue) believe are the main criteria/elements that should be known, so these specific concepts may be taught to the general public.

The recommendations from the community groups were used to validate the initial interface designs and to enhance and guide the development of the interface.

Initially the TUI touch table system was designed with a prefix component specifically chosen to appeal to bushfire community groups rather than to the general public. The prefix utilised the Bushfire Risk Assessment Model (BRAM) Likelihood layer developed by Parks and Wildlife Department of Primary Industries Parks Water and Environment DPIPWE (Figure 24) as an attractor for the application. It was thought that BRAM would appeal to residents as it predicts indicators for bushfire. The BRAM layer was controlled with transparency slider, so that it could be faded in and out of the other displayed map information.

The supposition was that once residents used the system for their own purposes then they would be likely to advise how the system could be customised to suit general public.

The suggestions were to include style, layout, recommended information and key features of lessons to be taught.

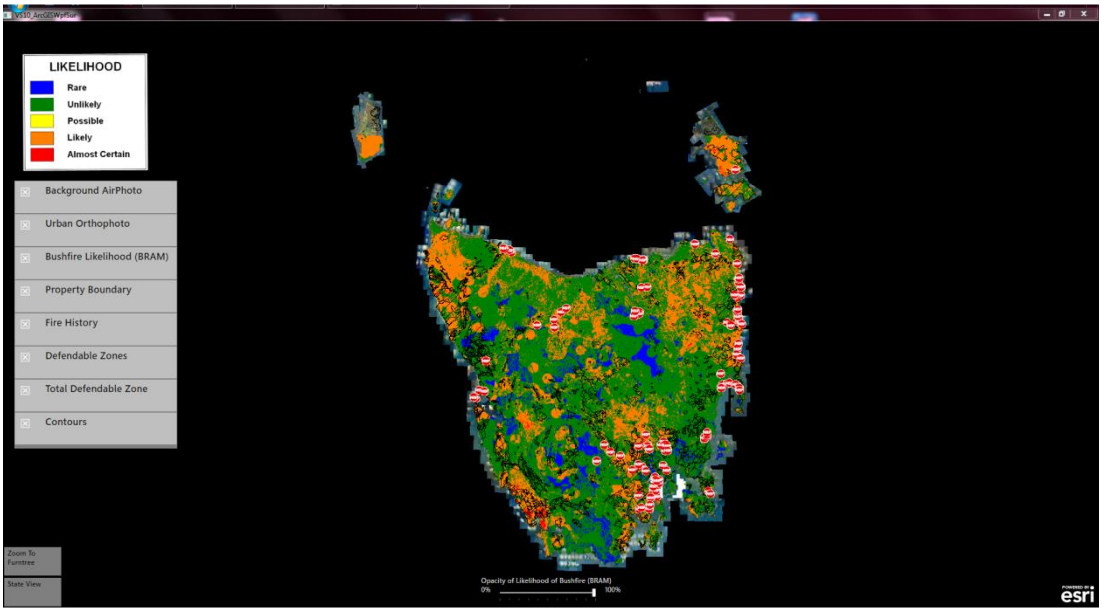


Figure 24: The BRAM Likelihood modelled map layer showing bushfire likelihood at regional level. Orange and red indicate areas of greater likelihood, while green indicates unlikely areas.

Inclusion of the BRAM Likelihood layer was a deliberate action to engage the group members. Once engaged, they would be questioned about potential use for general public. This resulted in a win-win scenario for both parties.

4.7.1.1 Representational Balance within the Participatory Research

This stage utilised extensive action research which focused upon at-risk bushfire community groups. Such groups were ideally suited to provide feature and function parameters for the general public final application.

The Tasmanian landscape is physically diverse. Climate, landform and vegetation coverage varies substantially across the state. For this reason, project consultation was sought from at-risk bushfire community from each of the three Natural Resource Management (NRM) regions in Tasmania (Figure 25).

Figure 25: Location of bio-risk communities (one road in/out higher risk because of the road network and surrounding landscape) that participated in the development stage of the study.

All community group work was undertaken with close association with the Tasmania Fire Service Bushfire Ready Neighbourhood program, who selected the focus community groups. The chosen groups share the following selection criteria:

1. BioRisk – The community is at risk because of their environment – specifically: There is only one road in and one road out, other escape avenues are restricted by the surrounding landscape.
2. An established bushfire community group that has met previously and
3. They are part of the scheduled ongoing bushfire education program.

4.7.1.2 Lilydale

The first group to evaluate the system was the Mountain Road Lilydale group (Figure 26) at Lilydale Fire Station November 5th 2013 7-8:30pm.

A brief report on the meeting including agenda, user comments and recommendations is in Appendix 2.

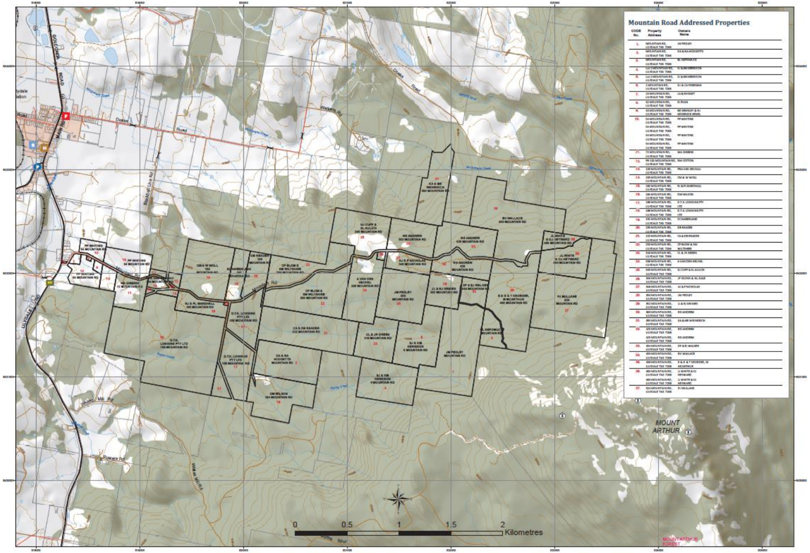


Figure 26: Location Map for Lilydale properties involved in community consultation at Mountain Road Lilydale.

Immediately prior to the meeting the presenters and fire brigade staff were given a brief demonstration of the tangible touch interface. At the end of the demonstration the workshop presenters decided to abandon their pre-prepared presentation (using PowerPoint on a wall projector). Instead they conducted the entire workshop solely using the touch table with Interactive Mapping. They replaced non–specific general examples from their presentation with relevant specific examples using local scenarios using the aerial photography, fire history and other spatial layers from the interface on the touch table (Figure 27). One of the presenters was the local brigade chief who used his extensive knowledge of the local region to present numerous bushfire scenarios using the table.

Figure 27: TasFire presenters using the tangible touch table interface for Bushfire Preparedness Training at Lilydale Fire Station.

The idea to use *instructor led training* as part of the general public exercise arose from watching the workshop presenters in action at Lilydale. They presented local scenarios, showing cause and effects on the table to demonstrate appropriate actions for a variety of scenarios specifically tailored for Lilydale. Each resident present used the table to view their own situation, while some neighbours held in-depth discussions planning future bushfire mitigation work.

The residents and brigade staff agreed the tangible touch table system concept valuably contributed to the education value of the workshop. Although they mostly focussed on the community perspective, they believed the concept could engage the general public.

> It is a valuable tool especially in the area of community engagement which was enhanced by the Table. Its' use enhanced clarity & understandings of fire behaviour concepts to community members, achieved recognition of the importance of Fire protection planning to community members and made the presentation of overall information more easily understood. Dave Cleaver, Brigade Chief Lilydale

4.7.1.3 Lorinna

Lorinna is an isolated off the electrical grid community at high risk in a bushfire because of a 8km one lane 20km/h speed restricted dirt road (Figure 28) that limits access to the township. For this reason Lorinna is a BioRisk area specifically targeted for bushfire education by the Tasmanian Fire Service (TFS).

Figure 28: The only road into and out of Lorinna.

The meeting held in the local hall (Figure 29) was attended by 26 people and one dog, down from 45 attendees in the previous year. Although TFS personally met with 20 families in the previous year to help write draft bushfire plans only 2 had complete written plans, in-line with the 9% national average (Mackie et al. 2013).

Figure 29: Bushfire Ready Neighborhoods meeting in the local hall at Lorinna.

A brief report containing agenda, summary statistics from the questionnaire competed by 13 residents and recommendations for the tangible touch table application is in Appendix 3.

Figure 30: The interface for Lorinna showing the property boundaries and contours.

The tangible touch table map-based *Preparing for Bushfire* application differed from the Lilydale version because it included property boundaries and contours (Figure 30), but also used local stored spatial datasets, because Lorinna does not have Wi-Fi or phone reception. The application was well received. Every attendee used the application. Without exception, every adult immediately navigated to their own house to discuss their situation. Only after this discussion was complete did they expand the consideration to the community perspective. The residents were actively engaged with the system for its purpose of how it could benefit them to prepare for bushfire:

- 'Interesting to see the area required for cleaning around the house. Able to put homes in perspective to [the] environment.' *Participant no. 6*
- 'To see the fuel loads made you think how best to deal with removing it.' *Participant no. 5*
- 'Easy to see the clear overall picture' *Participant no. 12*

The questionnaire responses show that 100% considered they learnt something about preparing for a bushfire from using the interactive surface combined with the presentation by the Tasmanian Fire Officers. Furthermore 100% felt motivated or inspired to undertake preparations in case of bushfire.

The residents made the following recommendations:

- Would be beneficial to show fuel load,
- Include topography, or road names,
- Add ability to switch to Google maps,
- Add in water sources,
- Include wind,
- Include more recent airphoto images,
- Create a simulation animation that shows a bushfire approaching then entering the local region, show the progression of the fire through the local region. Preferably in 3d so that the impact of slope is clearly demonstrated. Match the fire progress to a time scale that is adjustable (slider for faster, slower, pause).

The residents indicated they thought the table application was better suited for community groups rather than the general public. They indicated their perception that the general public would not care enough to justify the effort spent on the application. Several members suggested that the general public may be more interested if the application showed Tasmanian examples with animated bushfire graphics showing the effect of various fire scenarios.

4.7.1.4 Ferntree

The area of Ferntree is an outer suburb of Hobart, located in the dense tree covered hills to the east. The residents consider themselves to be peri-urban, rather than urban residents. The residents live more closely together than in Lorinna or Lilydale (Figure 31). The Ferntree community has a strong sense of danger from bushfire deriving mostly from a history of devastating bushfire in the area. There are 18 active community groups in the Ferntree area broken down by road segments. The tangible table interface was evaluated by the Westringa Road Fern Tree group, who were deemed to be representative of the area by TFS.

Summary reports and a full transcript of the first meeting is available in Appendix 4.

Figure 31: Houses in the Ferntree area near Hobart.

The table interface used live online data layers from theLIST (The Land Information System Tasmania) and custom community information (location and size of water tanks and fire hydrants), furthermore the defendable zones were calculated exactly to specifications allowing for changes in slope from the front, sides and rear of all buildings. The Ferntree region has complex topography, with numerous gullys and steep slopes dropping away from groups of houses. The surrounding vegetation has tall trees with shrubby undergrowth (Figure 32).

Figure 32: Typical vegetation surrounding houses in Ferntree.

The group found the tabletop application useful, engaging and motivating as evidenced by the comments from the post meeting questionnaires:

- 'Helpful - built on existing knowledge and familiarity with the area' Participant no 2
- 'It was probably more engaging than just seeing the info on a piece of paper. It was good to be able to switch sizes and maps.' Participant no 10.
- 'It was motivating to see the lay of the land and where we should be reducing fuel.' Participant no. 9

The group members were eager to contribute to recommendations for public education of *Preparing for Bushfire*. Sample constructivist tasks were demonstrated as a concept using model tangible rake and chainsaw objects. The group endorsed the concept and then advised that the sample constructivist tasks would only be suitable if the examples were real world scenarios and the feedback was immediate and informative. They suggested the house object be actively used as part of these tasks, perhaps to display the ideal solution.

Recommendations from the group:

- 'The no 1 most important action is to plan for bushfire– then make sure everyone in the house knows it well.'
- Create a set of exercises using real world scenarios that show inner and outer Defensive Zones during the exercise.
- Colour code the Defensive Zones. Use colour to indicate which parts need attention around a house. Watch colour rating change from red to green.

- Make the whole session short, no more than 15-20 minutes,
- Let it work for families and individuals and
- Modify the map to add scalebar and compass.

4.7.1.5 Working with Industry – TFS and State Fire Management Council

This study worked closely with Peter Middleton Community Development Coordinator, Community Education, Tasmania Fire Service (TFS), during the initial consultation process with the community groups.

However, after the first deployment to the general public (Section 4.8.1) below, an internal TFS Bushfire Ready Neighbourhoods Advisory Committee meeting made the recommendation that the research study gain further input from Community Protection Planning and the State Fire Management Council.

The meeting was coordinated on 6th May 2014 11:30-12:30 with representatives from Community Protection Planning (CPP), State Fire Management Council (SFMC), Tas Fire Community Development Officer Community Education and the author of this thesis (Transcript available in Appendix 5). The committee was concerned about the manner in which the touch table would be implemented for public use. They stated that they were aware that touch tables are purposely designed for standalone unsupervised use – simply walk up and use - where autonomous (passive self-monitoring/controlling) modules were activated. The committee expressed their apprehension by the following recommendation - 'We do not recommend using autonomous modules for Preparing for Bushfire on the Interactive Touch Table BECAUSE there is no check – 100% verification – that the subject matter is understood correctly by those who use it. The unanimous preference is an instructor led system. '

This statement is further evidenced in the meeting by the transcript segment:

> SFMC – 'I do not believe that it will be effective when used unsupervised.' (CPP agreed)
>
> CPP – 'The education itself needs someone there to interpret and explain'
>
> CPP – 'Lots more value by interaction and Q & A immediately'

In addition, the members recommended reducing the teaching to target only a few concepts, rather than a broad range of information, because of the feedback from the

Kingston deployment. They also expressed a concern that modelled BRAM information was being taken too literally, hence instructed that BRAM is only available for view at regional scale (1:100 000) and not at property scale.

Summary of recommendations:

- Use Bing imagery rather than theLIST Imagery for up to date images, or use Google imagery,
- A Web service exists for Google earth for DPIPWE,
- Try ESRI World Imagery service,
- Use 250k Topo for Navigation layer,
- Use *Bushfire Prone Areas Mapping* from theLIST. (To be available imminently),
- Disable BRAMS at community scale (1:100 000) and
- Do not use autonomous modules without an instructor present.

The committee stated that they fully expected that the between subjects method would fail because they believed that the general public would only be interested in the touch table, rather than watching the TFS educational videos and emotive TV adverts which they have probably already seen many times.

The committee stated they fully support and encourage future deployment and implementation of the TUI touch table system with the changes as indicated.

4.7.2 Contribution to the Research from Participatory Research

The community groups and industry recommendation for public awareness sessions is summarised as:

- Use real world local scenarios as short tasks,
- Use map-based information,
- Use model tools, chainsaw, rake and house with immediate and informative feedback,
- Design the system for use with small groups and individuals,
- Use instructor led examples and
- Do not use a between subjects method instead try to use a comparative methodology,

4.8 Bushfire Application Development and Preliminary Deployment

4.8.1 Pilot Deployment of General Public Version at Kingston Shopping Centre

Kingston is a small town about 12 km south of Hobart, Tasmania. It is a central hub for the surrounding rural communities with restaurants, LINC Library and two shopping centres. The location makes Kingston a suitable location to evaluate the table interface.

The tangible touch table was deployed in a vacant shop as part of a week-long multi-purpose display of 1967 bushfire photos and a Resilience Photography Competition. The presence was advertised on local radio, on a multi-channel TV news item, on a display billboard outside the shop, on flyers and by word of mouth from guests attending the opening presentation night (Figure 33).

Figure 33: The opening night at the Kingston shopping centre site where the table was deployed.

At this installation, the table exercise was designed as a between subjects method, where participants would use either the tangible table or traditional Tasmanian Fire Service (TFS) bushfire education materials (Table 4). Participants were alternated between systems. This configuration is not the final form of the exercise used in this thesis.

Table 4: TFS bushfire education materials

Take Home Message	Title	Source	Length	Order
How to prepare a Bushfire Survival Plan	Prepare a bushfire survival plan	2014 Bushfire DVD Online version: http://www.youtube.com/watch?v=pVLr6j4E3vg	1 Min 20 Sec	1
Make a Bushfire Plan	Make a Plan	TFS 2014 Bushfire Safety - MAKE A PLAN (Emotive Radio Version) http://www.youtube.com/watch?v=Fkla4WsT9OQ	15 Sec	2
Wind can change direction of bushfire quickly	Wind	TFS 2014 Bushfire Safety – WIND http://www.youtube.com/watch?v=579Vx2s47EU&list=UUtNx_e2jgDShjt9evUgdaaw	15 sec	3
Smoke impedes evacuation, so leave early to avoid smoke	Dangers of Smoke	TFS 2013 Bushfire Safety - Smoke (Emotive Radio Version) http://www.youtube.com/watch?v=53kRfsnARsM&list=UUtNx_e2jgDShjt9evUgdaaw	30 Sec	4
Know where your nearby safer places are, and how to get to them.	Safer Places	TFS 2014 Bushfire Safety - SAFER PLACES http://www.youtube.com/watch?v=w5qpkARyJ-I&list=UUtNx_e2jgDShjt9evUgdaaw	30 Sec	5
Leave as soon as possible. Travel to NSP	If you plan to leave, leave early	2014 Bushfire DVD Online version: http://www.youtube.com/watch?v=ZEORhTi9Fe4	2 Mins 30 Sec	6
Don't leave at the last minute	Why people die in bushfires	2014 Bushfire DVD Online version: http://www.youtube.com/watch?v=ZdqkNYkOVys&list=PL896C10EBEE467D02&index=6	30 Sec	7
Create a defendable space to provide best chance for your home to survive a bushfire.	Create a defendable space (Prepare to survive)	2014 Bushfire DVD Online version: http://www.youtube.com/watch?v=vZ5T6IJttyw	4 Mins 30 Sec	8

The questionnaire process gathered information about their predisposition to bushfire, their current level of preparation for bushfire, their perceived level of expertise, how long they lived in the area, along with engagement questions about the interface. The running sheet for this exercise is available in Appendix 6.

Only 20 participants completed the exercise. However every participant refused to undertake the traditional method of viewing the TFS bushfire education materials. Most indicated that they had seen them already, or stated they were only interested in the tangible table application. Typical responses included: 'I have heard the ads', 'The DVD was sent out to all of us' and 'I want to look at this (motioning to the Touch Table)'.

The post exercise questionnaire (Appendix 7) results show the participants registered very high levels of engagement with the interface and the tangible objects. The learning summary in Table 5 showed positive results, however, the exercise was unable to compare these results to the established traditional methods so this deployment was treated as a pilot study. Furthermore there was the possibility that the nature of the multi-purpose exhibition acted as a filter so that the members of the public who entered the room were predisposed for bushfire, rather than being a representative sample of the general population.

Table 5: Responses from Kingston participants for the adult learning questions.

Learning Summary	%	Response
Do you believe that you learnt something about preparing for a bushfire from using the interactive surface with the objects?	100%	Learnt or May be Learnt
Did this experience inspire or motivate you to undertake preparations in case of bushfire?	70%	Motivated
How beneficial is using recent aerial photography of the local region for the examples?	100%	Essential or Very Beneficial
How much did the Interactive Mapping help you to understand the concepts of Preparing for Bushfire?	95%	Essential or high level
Is the application topic of *Preparing for Bushfire* directly relevant to local residents?	90%	Relevant
Did using the Interactive Table system influence discussion or interplay between group members?	100%	Yes

The lessons learned from this experience guided a redesign of the comparative methodology including the change to a within subjects approach.

4.8.2 Lessons Learnt from the Kingston Experience

The positive outcomes were:

- The tangible touch table *Preparing for Bushfire* system was found to:
  - Be engaging,
  - Demonstrate adult learning traits (motivation, perception of learning) (Knowles et al., 2005) and
  - Be accepted as a worthwhile endeavor:
    - 'Wonderful. Should be statewide.' Participant no. 10,
    - 'You should come to our bushguard meeting in Kettering and show the others.' Participant no. 17
    - 'Excellent concept - should be a great educational tool' Participant no. 2
- The constructivist task using the chainsaw and rake models was well received:
  - 'The physical objects really make the difference. It makes it easy to remember - and not zone out.' Participant no. 15
  - '[objects] Engages and deepens the thinking between what is on the ground at home and the simulation.' Participant no. 5
  - 'Made interacting with the system a no brainer' Participant no. 2

The negative outcomes presented an opportunity to refine the comparative experiment, to reduce these negative influences.

The general public's behaviour was less consistent that anticipated, which demonstrated that the revised exercise must be more rigorous next time. The following was noted about the participants:

- About one third of the people who visited the shop looked at the table.

- On the opening night there were too many people simultaneously using the table, therefore no one could undertake the exercise without interruption. No questionnaires were completed, so no data was gathered regarding the table interface.
- Many visitors stated they were too busy to complete the exercise with the questionnaire, yet often they stayed using the tangible table system and discussing bushfire preparations for longer than they would have spent completing the exercise and questionnaire.
- Approximately one third of those who completed the exercise were referrals from visitors who had told them about the bushfire tangible interface.
- All participants did not want to use the traditional methods and were only interested in the new tangible touch table system.
- 8 participants refused to answer the post-test as they *felt they already knew the answers* – yet for many the pre-test showed incorrect answers while review of audio session recording showed the participant stating the true answer.
- The library LINC site next door to the shop site had many more visitors, than the shop in the shopping centre. The LINC also has constant Wi-Fi.
- Although over 1100 properties (Figure 34) were digitised to use as local examples during the entire week, however only 2 visitors were owners of the properties.
- An 84 year old man operated the interface easily while discussing past bushfires in the region. He had never previously used a touch device and did not own a mobile phone.

Figure 34: Peri-urban properties, indicated in yellow , on the Tinderbox peninsula below Kingston.

Many users of the system commented that the map-based constructivist tasks needed further development for visual feedback, function and practicality.

The critical failure points which needed to be addressed in the methodology were:

1. Using a between subjects approach rather than a within subjects approach which would have forced the participants to use both systems,
2. There was likely too much influence from instructor potentially biases learning gains. By correcting the participants they were probably given the answers which reduced any measurable learning gain.
3. The exercises were extensively freeform using examples closely resembling their own house. Standard structured examples with practical exercises which recorded their response would establish a consistent easy to compare method to quantify changes.
4. No mandatory requirement existed for all participants to complete all tests.

Kingborough council, as an independent observer, were pleased with the deployment. A letter from their Mayor (shown in full in Appendix 8) states that from their observations alone, the council believed the tangible table interface was successful.

4.8.3 Design of the *Preparing for Bushfire* Interface

The recommendations from the community groups (Section 4.7.2), the Kingston deployment (Section 4.8.1) along with the design guidelines from Sections 4.6.1, 2.6.3, 4.6.3, and 4.6.4 are applied to the *Preparing for Bushfire* interface design which is then shown in Figure 35.

The *Preparing for Bushfire* interface design (Figure 35) was optimised to maximise the screen area for the map display as this perpetuated the metaphor of a map overlaid on a table. A map laid out on a table is a familiar concept requiring a familiar skill set. It perpetuates expectations for what can be seen and how it can be used, only this map will not blow away. In fact it can do so much more than a printed map including change the map extent, scale, map theme, add and remove map layers and when models are placed upon the map it interacts with them.

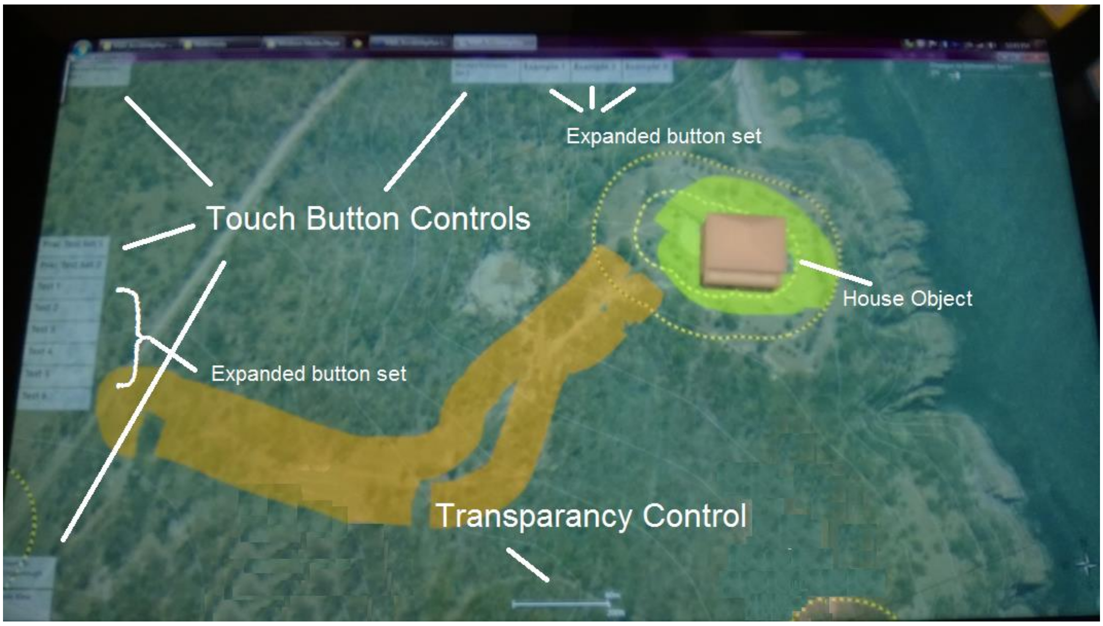


Figure 35: The tangible touch table interface for the *Preparing for Bushfire* exercise. Note the touch buttons around the outside of the display. The lower 6 buttons on the left hand side are currently visible as they are activated as the expanded options of a single button.

The interface was controlled by touch buttons, object interaction and by finger touch gestures. The interface touch buttons were only displayed around the edges and several only displayed when called from a menu choice. All the buttons were labelled with black text on a grey background. The colour combination was chosen as it was distinct enough to be easily read, yet be subtle on the map background. To aide this further the buttons were partially opaque to reduce the contrast between the buttons and the background map.

The touch buttons only existed for the purpose of exercise controls for the investigator. Each button resets the display to zoom to a specified location at a set scale. They were grouped into the two sets of worked examples across the top of the screen and the two sets of practical tests, along the left hand side of the screen. The two controls in the bottom left hand corner reset the display to the statewide view and to the region of the local examples. The only other finger touch control is a slider at the bottom centre which adjusts the transparency of the solution to the current displayed exercise used by participants.

The interface controls for the participants are finger gesture and object controls. The only non-gesture finger touch control is a slider bar that controls the transparency of the solution. Map controls are standard smart phone gestures:

1. touch and hold finger to move the centre of the map,
2. finger swipe to pan and
3. two finger sweep together (or apart) to control zoom.

The interface uses three object controls: a house, rake and chainsaw (Figure 37). These are described in detail in Section 4.9 Design of Map-based Constructivist Exercises using Tangible Objects.

4.8.4 Animating the Impact of Bushfire Preparations

The interface objects of the rake and chainsaw objects (Figure 37) are designed to work as rake and chainsaw tools in the interface. The rake sweeps, so operates by placing the rake head on the photo image and sweeping. Similarly the chainsaw uses a cutting action. It takes several attempts to cut a tree and the chainsaw cutting action is usually applied in a series of cutting gestures, where the tip of the chainsaw is placed on the surface and dragged for a short distance, then picked up repositioned and a new cut is made. The areas touched by these tools indicates where preparations for bushfire are made (Figure 36).

Pilot testing showed a strong preference for the rake and chainsaw to replace existing vegetation in air photos with less vegetation that accurately reflected the changes. For example using the chainsaw on an area with trees would transform into an area with fewer trees of exactly the same present type. The problem with this solution is many different varieties of trees exist, so it is a very resource intensive process to cater for all tree types. A process that cannot be automated. The standard method to produce this effect is created by a two-step process:

1. Initial pre-processing to generate a new image of each air photo showing clear areas with balanced vegetation in place of forest and thick vegetation. The new image shows how the photo would look if the all the vegetation was selectively cleared applying the rules for defendable zones. This image shows all the clearing and vegetation changes. This step must be complete prior to starting the interface.
2. When in operation the rake and chainsaw act as a mask/window that shows the ideal solution image (from step 1) displayed only in the paths traced by the rake or chainsaw.

3. This has the affect whereby the displayed image of the original photo looks like it is changing as the rake/chainsaw moves around the image, because clearing appears in the place of vegetation as the rake/chainsaw moves.

This solution will only work on current air photos. It means that new solution images must be created whenever new air photos are made available. It also means that the rake and chainsaw will only work where the solution air photo images have been modified/created. It is limiting and restrictive.

Figure 36: The result after the rake and chainsaw have been used to indicate recommended changes to prepare for bushfire. The orange indicates areas to chainsaw, while the vibrant green indicates areas to rake.

An alternative is to paint a standard cleared image of the ground where the rake is used and to paint a standard cleared image of reduced vegetation where the chainsaw is used. This method was trialled and disliked by the users because it looked out of place on most of the air photos. The colours, shading, brightness and vegetation usually did not match the air photo being drawn upon. This solution looks most realistic when the colour of the replacement images closely matches the air photo background. Unfortunately, Tasmania has a diverse vegetation coverage so the standard solution image rarely matched the actual vegetation background, hence this alternative is not a viable solution.

The next option used only a single colour for the swath paths of the chainsaw and rake tools. This was deemed acceptable by pilot testers. It was easily implemented, worked universally across the state, meant the user scenarios could be applied to all properties. Plus a separate colour could be used for the rake (green) and for the chainsaw (orange) (Figure 36).

4.9 Design of Map-based Constructivist Exercises using Tangible Objects

This section explains the logic of the design of all elements of the map-based constructivist exercises. These hands-on practical exercises are undertaken by the participants using tangible physical model objects (Figure 37) that interact with the interactive map on the touch table. The exact instructions are explained as a written script in Chapter 5 Experiment Implementation, Section 5.2, while some sample solutions are explained in Section 6.8.1 Examples of Completed Worked Examples and Practical Exercises.

The lessons learnt from the Kingston preliminary system pilot test (Section 4.8.2) were applied to the preliminary map-based constructivist exercises. The exercises were expanded for use with directed questions rather than free form. In addition, Interface objects tools were integrated into the exercises including more tools with enhanced speed and precision.

The map-based format is well suited to present information about landscapes, environment and people within the sphere of influence. Bushfire is directly affected by all three of these criteria.

The exercises are groups of three short bushfire scenarios for properties displayed on maps that are completed by the participant using tangible objects and Interactive Mapping to assist in explaining their answers (Listed in Table 6 and shown in Figure 40 and Figure 41).

Three tangible objects are used within the interface by the participants. These are a house, rake and chainsaw (Figure 37).

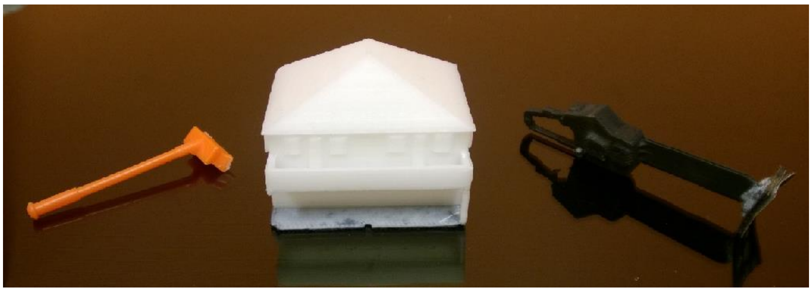


Figure 37: The interface tangible objects.

The house object displays the defendable zones around the buildings in the air photos. The defendable zones are shown as dashed lines. The inner zone is 20m from the house, while the outer zone is 45m. The house object is the only way to activate the defendable zones. A house model was chosen because a primary goal is to prepare the property so the house does not burn down and because people attach a large sentimental value to their home. Another reason is because the defensive zones are measured from around the house. The design of the house was chosen from several styles to be representative of a rural house. The model was 3d printed because of the high appeal of 3d objects to adults, as observed from 9 months of public demonstrations (Appendix 1 Section A2.3). The house was left white because it provides the greatest contrast against underlying air photo images, which rarely contain white (Figure 38).

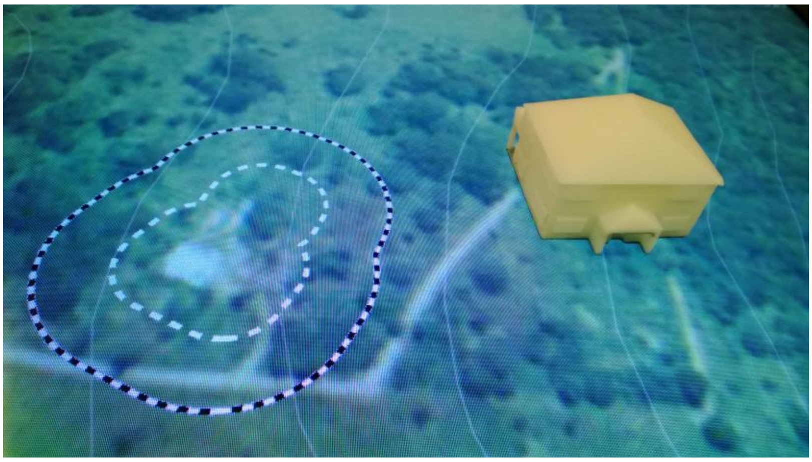


Figure 38: The house interface object placed upon the surface turns on the buffer zone lines of the defensive zones on the airphoto.

The rake and chainsaw are used to depict clearing of bushfire fuel in the defensive zones displaying the impact of preparations on the display (Section 4.8.4). These tangible tools operate using actions as they would in the real world. The rake sweeps, so operates by placing the rake head on the photo image and sweeping. Similarly the chainsaw uses a cutting action. It takes several attempts to cut a tree and the chainsaw cutting action is usually applied in a series of cutting gestures, where the tip of the chainsaw is placed on the surface and dragged for a short distance, then picked up repositioned and a new cut is made.

The tangible model tools have a tight metaphor between their physical design and purpose because of their high fidelity and function which is easily interpreted 'as a way of visualizing an operation' Sharp et al., (2011, p.46). Visualisation is aided by the tools as observed by Marshall, (2007, p. 165) who states :

> In expressive activities, learners create an external representation of a domain, often of their own ideas and understanding. Tools can help learners to make their ideas concrete and explicit and once externalized, they can reflect upon how well the model or representation reflects the real situation. This description of expressive learning has much in common with Papert's [38] theory of Constructivist learning.

The exercise tasks are real actions, clearing leaves and bark, removing trees and ember-proofing. These tasks appeal to adults because as we know from Knowles et al. (2005, p.67):

> Adults are motivated to learn to the extent that they perceive that learning will help them perform tasks or deal with problems that they confront in their life situations. Furthermore, they learn new knowledge, understandings, skills, values and attitudes most effectively when they are presented in the context of application to real-life situations.

The solution to the exercises requires applying spatial reasoning which is an established component of empirical TUI studies with adults (Section 4.6.1). The knowledge that map-based exercises include spatial reasoning was one of the deciding factors for employing the technique. The actual solution is available after each task is completed (Figure 39). A slider at the centre of the bottom of the screen controls the opacity of the solution, so the participant may fade the solution in and out with their own answer.

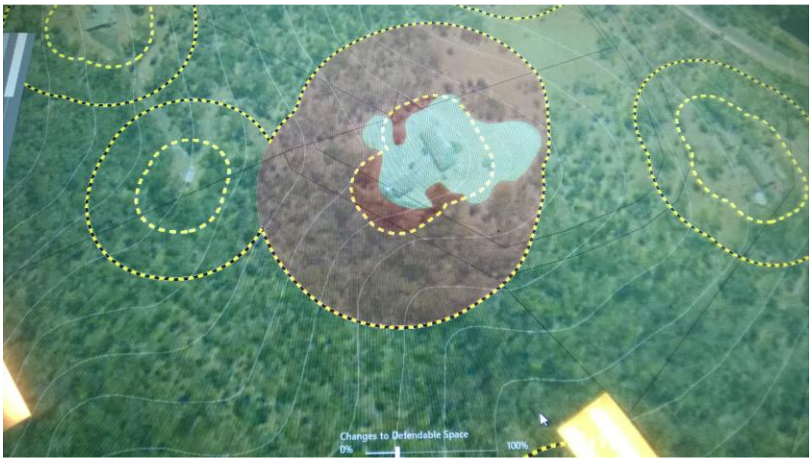


Figure 39: The solution for a task scenario is available by changing the opacity set by the 'Changes to Defendable Space 'slider (centre bottom).

The map-based constructivist tasks were designed with consideration of the eight constructivist instructional principles suggested by (Savery & Duffy, 1995):

1. Anchor all learning activities to a larger task or problem.
2. Support the learner in developing ownership for the overall problem or task.
3. Design an authentic task.
4. Design the task and the learning environment to reflect the complexity of the environment in which learners should be able to function at the end of learning.
5. Give the learner ownership of the process used to develop a situation.
6. Design the learning environment to support and challenge the learner's thinking.
7. Encourage testing ideas against alternative views and alternative contexts.
8. Provide opportunity for and support reflection on both the content learned and the learning process.

The task design meets each of these criteria in the following way:

1. *Preparing for Bushfire* is a small component of bushfire risk, which is an increasing problem in Australia.
2. Bushfires spread and affect all inhabitants.
3. The scenarios are real situations from within Tasmania.
4. The tasks use local real world air photos, contours and property boundaries.
5. The participant controls the task interface tools.
6. There are three levels of problem complexity.

7. Ideal solutions are available, as well as solutions for extreme circumstances as depicted by Fire Officers.
8. The questionnaire after the exercise supports reflection of the content within the exercise.

Although, the tangible objects operate at any time on the interface, they are designed to only be used during the worked examples and practical exercises. Tangible object Cubes are used to display the Static Maps. One cube each for the worked examples, and the practical examples. Each side of the cube activates one of the six examples.

The constructivist tasks are divided into two types of examples: worked examples and practical tests. There are two practical tests which are equivalent. These are used in an alternative sequence for the interim test and the post-test. The tests are comprised of two sections: factual recall and practical applied exercises. The practical section exists to evaluate how participants apply their new knowledge by evaluating scenarios. This process uses the 6 mutually exclusive scenarios listed in Table 6. The task scenarios were reviewed by enlisting fire education expert Peter Middleton to review and validate the task scenarios.

Table 6: Properties used for the practical exercises.

Scenario Number	Description	Group Type	Key Points (Correct Responses)
1	House on flat land with no surrounding vegetation in the defendable zone or nearby surrounding area.	Single House flat land	No work required Danger – from cut off escape route OR The surrounding paddock is high grass and fire races through the paddock. STAY or LEAVE
2	House on flat land surrounded by continuous vegetation in both defendable zones and surrounding area	Single House flat land	All actions required Danger – Continuous veg in inner zone LEAVE
3	Single house on steep slope of hill with vegetation in the defendable areas.	Single house on hill	All actions required Danger – surrounding vegetation LEAVE
4	Single house with continuous vegetation at back of house	Single house on hill	Remove Trees in Inner Zone behind house, Prune

	starting at the break of slope from a steep hill		under Trees to higher than 2m from ground. Danger – from fire on hillside LEAVE
5	Neighbouring houses with overlapping inner zone defendable space	Neighbouring houses overlapping defendable space	Inner zone relatively clear. Rake, move woodpile, prune branches, remove flammable shrubs. Outer Zone – remove lower branches, rake leaves. NOTE – Neighbours could work together. Danger – Surrounding bush LEAVE
6	Neighbouring houses with overlapping outer zone defendable space	Neighbouring houses overlapping defendable space	Inner zone relatively clear. Rake, move woodpile, prune branches, remove flammable shrubs. Outer Zone – remove lower branches, rake leaves. NOTE – Neighbours could work together. Share fence has vegetation between properties. Danger – Surrounding bush beyond outer zone. LEAVE

The following three questions are asked of the participant for each task in the exercise:

Q13 What actions do you recommend to prepare this property for bushfire?

Q14 What is the greatest danger to the property?

Q15 What would you do in the event of SEVERE bushfire if you lived here? Stay or Leave?

The stay of leave question (Q15) is deliberately asked last because by this this time the participant would have analysed both the present and future position of the property, hence would be aware of all the agreements for staying or leaving in a bushfire.

Each test contains three self-contained scenario tasks with feedback. Each scenario task has increasing difficulty and complexity, slowly advancing knowledge required to successfully answer each scenario. The two sets are below as Figure 40 and Figure 41.

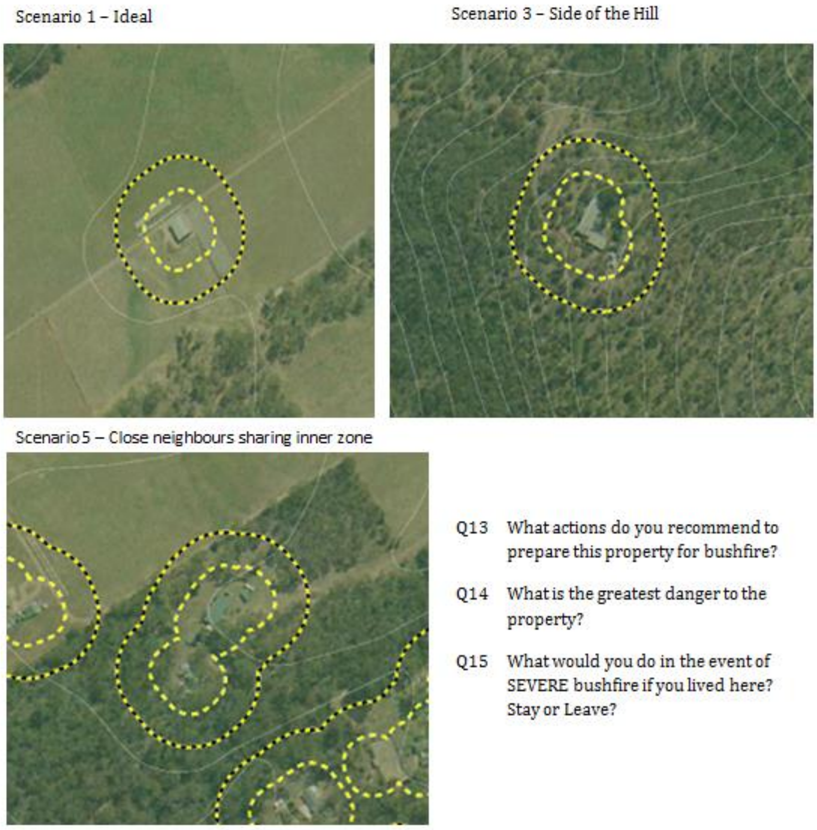


Figure 40: Practical test set 1 showing the map images for each scenario.

Figure 41: Practical test set 2 showing the map images for each scenario.

In table 5 the group type is synonymous with complexity. The scenario numbers in the figures correlates with the description in the table.

The following examples, although similar to the tests, are the worked examples. They are broader than the practical test examples. The worked examples are task scenarios for training purposes after the bushfire video so the participant has the opportunity to practice what they have learnt in a real world situation. These worked examples (Table 7) are grouped into two equivalent sets of three task scenarios – one easy, medium and hard. All scenarios work with the tangible tools of the house, rake and chainsaw. In addition the scenarios also have an available solution.

All examples were approved by TFS education and are actual Tasmanian properties.

Table 7: Properties used for the worked examples.

Scenario Number	Description	Group Type	Key Points (Correct Responses)
1	Farm house on flat land in the middle of a paddock with no surrounding vegetation in the defendable zone or nearby surrounding area.	Single House flat land	No work required Danger – from cut off escape route OR The surrounding paddock is high grass and fire races through the paddock. STAY or LEAVE
2	The house is a Bowls Club on flat land surrounded by well cleared grounds in both defendable zones. The surrounding area is covered with vegetation.	Single House flat land	All actions required Danger – Road way in may be blocked by falling trees. Only need to rake and ember proof the buildings as they are sufficiently clear otherwise. LEAVE
3	Large house on long thin block dense tree lined driveway with some vegetation in the defendable areas.	Single house with driveway issue	All actions required Danger – driveway and surrounding vegetation LEAVE
4	Single house on side of hill with another house behind that has a right of way on the road to the first property.	Single house with driveway issue	Remove Trees in Inner Zone behind house, Prune under Trees to higher than 2m from ground. Ckear away further down the slope in front of the house. Clear vegetation away from the road Danger – from fire on hillside LEAVE
5	Urban house neighbouring reserve	Complex situation	Inner zone overlaps with neighbours and the reserve. Make rake only in the park, Outer Zone –extensively overlaps with the reserve NOTE – long winding escape route Danger – Surrounding bush

			LEAVE
6	Conningham beach – property next to walkway near beach.	Complex situation	Inner zone on the property is relatively clear. Outer Zone – shared with neighbours and the walkway. NOTE – Neighbours could work together. Danger – Escape from Conningham beach is a long road. Do not go to the beach. The vegetation is too dense so the radiant heat will be too hot. LEAVE EARLY

The worked examples are controlled by a set of touch buttons (Figure 35). One button for each set expands into a touch button for each scenario. When activated the map display navigates to the location of the worked example. The map is fully interactive for touch navigation and tool interaction. The maps of the worked example set one is visible in Figure 42.

Figure 42: Worked examples set 1.

In Static Map sessions the same worked example sets are used. The examples are displayed at the same initial scale as they are displayed for Interactive Mapping. However, Interactive Mapping is not available and the interface tools do not work. The worked examples for set two are shown in Figure 43 as they look for the Static Map mode.

Figure 43: Worked examples set 2.

In Static Map mode all touch interaction must be disabled for the participants, which presents the problem of how to control the interface to display the required static maps. This is solved using tangible objects. Touch control on a PixelSense categorises touches into three styles: finger, object, and Microsoft Tags. As Microsoft Tags are proprietary for the PixelSense isolating touch for Microsoft Tags eliminates all touches by fingers or everyday objects (e.g. clothing, bracelets). Large cubes are an ideal tangible object for displaying the map sets (sets of three) because cubes have six sides therefore each cube could support six Microsoft Tags – one Tag for each map - hence one cube may control two sets of maps. Placing the map cube on the table surface actives a Static Map. The sides are labelled for easy identification.

In Static Map sessions the maps are displayed using map cubes instead of by touch buttons. Each map cube activates maps examples for one set, thus there are four cubes in all – two for practical test sets and two for worked examples. The map cubes are visible on the touch table bezel in Figure 44. The blue map cubes activate the Static Map worked examples sets, while the yellow cubes activate the practical test sets. The table in Figure 44 is shown in interactive mode, as observed by the house model in operation.

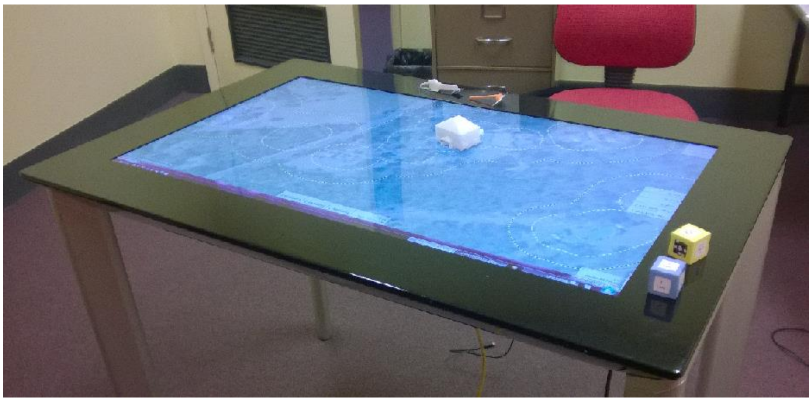


Figure 44: The tangible touch table in action with the house active on the interface. The rake and chainsaw are visible on the bezel behind the house. The blue and yellow cubes on the bezel control the interface during the Static Maps sessions.

The exercises are useful for TUI research because as noted by Antle (2012, p. 233):

> One area that may be revolutionized by tangible and touch technologies is hands-on problem solving in spatial domains. Focusing on theorizing and empirically validating design guidelines for spatial domains is novel.

4.10Traditionally Available Alternative

The closest traditionally available alternative is paper maps for the worked examples and practical examples. Printed maps perform an equivalent function as the Interactive Mapping table although without the zoom and pan ability. Maps are able to be used by a group as well as by individuals. The same level of detail and information is able to be printed on the maps as on the touch table. The printed maps will be of the same scale as the starting scale when scenarios are displayed on the touch table.

However, given the past experience (Section 4.8.1 Pilot Deployment of General Public Version at Kingston Shopping Centre) with dissent regarding alternative systems, the printed maps will be substituted with Static Maps displayed on the touch table. Static means that the map display cannot move by pan or zoon, or be enhanced by adding or removing digital map overlays.

The Static Map tasks are identical to the tangible touch table tasks. The participants are asked exactly the same questions for the practical examples and the worked examples.

In addition, the purely digital alternative has the advantage that there is no wear and tear from use, as there would be from paper maps.

4.11 Summary

This chapter outlines the logic and structure behind the proposed experimental design for the main general public deployment.

Early development work in stages one and two contributed to aspects of the design. Furthermore, theses stages empirically validated several the underlying premises:

- natural resource experts believe that the general community has a poor understanding of the interconnectedness of natural resources, and
- Adults engaged with and enjoyed the touch table map metaphor with tangible objects successfully applying spatial reasoning with explorative tasks ($X2$ $(3, N = 19) = 56.62$, $p < .01$).

Key results from stages one and were presented, however additional Detailed results and discussion of stages one and two is available in Appendix 1 for the interested reader.

The application topic for the experiment design in the general public evaluation has been selected as *Preparing for Bushfire* as is it a significant valid issue because of the direct impacts and high risk to residents and potential residents, and because of the complex relationship between bushfire and natural resource elements.

The chapter discussed the consultation with community group phase, which identified aspects of *Preparing for Bushfire* should be taught to the general public and recommended ways to do so.

The preliminary *Preparing for Bushfire* application was pilot tested with general public for a week at the Kingston shopping centre. The lessons learned from the experience fine-tuned the exercise method, measures, constructivist tasks and reporting mechanisms for the experiment design for the main deployment.

Importantly the rationale of the design of the map-based constructivist exercises was explained in detail, along with the design rules, functions, and purpose of the custom designed tangible interface objects.

The general public exercise is discussed in detail in the following chapter. The results of the general public exercise are presented in the chapter 6 and are discussed in the Interpretation and Discussion chapter 7.

Chapter 5: **Experiment Implementation**

"'It is still magic even if you know how it is done"

— Terry Pratchett

5.1 Introduction

In the previous chapter all elements of the research design process were justified and described. This included the crucial design of the map-based constructivist exercises

This chapter contains the full implementation procedure for the within subjects experiment for the general public. The procedures are presented in detail as they were implemented so that the exercise may be easily duplicated.

The experiment uses a multipart questionnaire as the fundamental source of measures of learning, engagement, and useability. This chapter contains a detailed explanation of the motivation and justification for every question in the questionnaire.

5.2 Experiment Structure, Implementation and Deployment

This section contains the plan of the experiment and the detailed implementation procedure. This exercise differs from the pilot deployment at Kingston (Section 4.8.1) as it incorporates strategies to avoid the encountered failure points (Section 4.8.2).

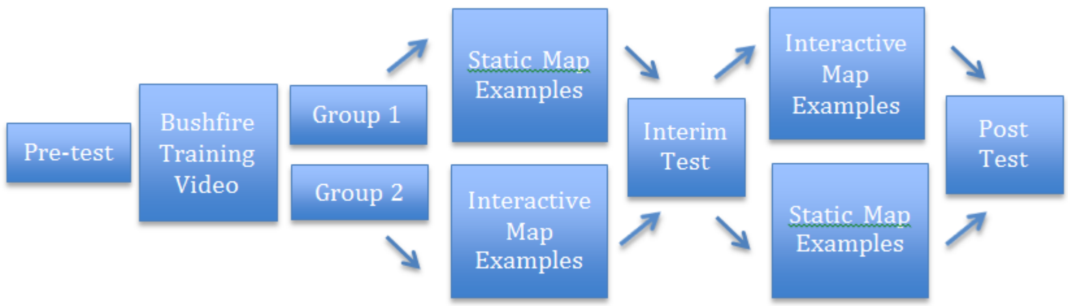


Figure 45: The within subjects design for the evaluation. All participants complete a pre-test, then watch the Bushfire Training Video. Participants split into groups. One group use Static Map examples followed by the interim test, then they swap to use the tangible Interactive Map examples followed by the post-test. Group two follow a similar format but use tangible Interactive Map examples first followed, interim test, Static Map examples, finishing with the post-test.

The general public comparative study is now a within subjects design comparing the Tangible *Preparing for Bushfire* interface (Section 4.8) using the map-based constructivist tasks (Section 4.9) to the traditionally available alternative (Section 4.10). The within subjects style means that all participants use the touch table. The map-based tasks are now standardised. Furthermore, they are always implemented exactly the same way with exactly the same scripted introduction and all have a stated directed goal. There is very little interaction from the instructor. The instructor's role is to introduce the scenarios and to explain the interface. They are not allowed to prompt the participant, or correct them as this may bias results.

The detailed system implementation procedure is listed step by step in Table 8 while Figure 45 shows the overall structure of the experimental process. These are presented so that other researchers can recreate the experiment for this research. Every participant follows the sequential steps listed in the table.

When recruiting participants it is important to mention that the average completion time is 53 minutes for individuals and 1hr 20mins for groups. All participants must have sufficient time to complete the session in one attendance.

Table 8: The implementation procedure for the experiment with the general public.

Step	Description
1.	Hand Participant Information Sheet to participant to read.
2.	Ask participant to read and sign Consent Form
3.	Novelty play,
4.	Answer section one of the pre-test in the questionnaire
5.	Answer section one pre-test practical component using the photos from NSW Bushfire education,
6.	Watch 4:30 min Tasmanian Bushfire Education video titled 'Create a Defendable Space'.
7.	Record the sequence number (Section 5.2.1) obtained from the pre-randomised list for this participant. Use this to identify the required cubes for the Static Map portion. a. Place the required Worked Example Cube and Practical Cube on the PixelSense Bezel.

	b. For this example assume sequence 4 (from Table 8). I Ex2 Test 1, S Ex1, Test 2 Participant Starts with Interactive Table using Worked Example Set 2 with Test number 1 (Practical Test Set 1) as interim test. The second phase switches to Static Maps using Worked Example Set 2 with Test number 2 as Final Test (Practical Set 2)
8.	Start Audio Recording
9.	Complete 3 Interactive worked examples (progressing from simplest to hardest) [Use the touch buttons, to activate each exercise by placing the appropriate face down on the surface.] a. Introduce the Interface Objects Sample dialogue for introduction of objects: 'You may use these models with the table (Indicate the house, chainsaw and rake). When you place the House on the table it shows the boundaries for the defendable space zones. These boundaries are calculated to include the correct slope for the house. The boundaries are removed when the house is removed.' b. Briefly describe each scenario at their start. Sample dialogue: 'Consider this property: It is at the base of a hill. The property boundary is here (quickly trace by finger), their access road is here (indicate by pointing), These white lines are 10m contours indicating the land is relatively flat in front of the house here, but steep at the back here.' c. Instructor records all pans, zooms and frequency of use of each interface object. d. Instructor asks the 3 standard questions for each scenario,

10.	Start interim test – (Test 1) Recall section. Participant is moved away from the table to a chair and desk where they complete the recall section of the test by writing the answers to 3 questions on the questionnaire.
11.	Return to the touch table for practical section.
12.	Complete 3 Practical Scenarios (progressing from simplest to hardest). Activate using the labelled touch buttons. State: 'You may use the interface at this point to help with your answer' For each scenario: Briefly describe each scenario at their start. Ask question 'What do you think is their greatest danger?' Ask question 'What do you think the owner could do to better prepare their property for bushfire?' Ask question 'In the event of a severe bushfire – would you stay or leave?' Instructor records keyword and phrase responses, all pans, zooms and frequency of use of each interface object.
13.	Switch to alternate system. If starting with Interactive switch to Static Maps, if starting with Static Maps switch to Interactive Maps.
14.	Complete 3 worked examples (progressing from simplest to hardest) [Use the cube objects, keeping with the TUI theme, to activate each exercise by placing the appropriate face down on the surface. Faces are labelled Worked Example 1, Worked Example 2 and Worked Example 3] Briefly describe each scenario at their start.
15.	Start Post Test – (Test 2 from sequence) Recall section. Participant is moved away from the table to a chair and desk where they complete the recall section of the test by writing answers for 3 questions on the questionnaire.
16.	Return to the touch table for practical section.
17.	Complete 3 Practical Scenarios (progressing from simplest to hardest). Activate using the cubes. [All touches, gestures and interface objects are

	disabled in the interface. Participants may still touch the table or use the objects but no visible effects occur.] For each scenario: Briefly describe each scenario at their start. Ask question 'What do you think is their greatest danger?' Ask question 'What do you think the owner could do to better prepare their property for bushfire?' Ask question 'In the event of a severe bushfire – would you stay or leave?' Instructor records keyword and phrase responses, and even though they do not perform any function still record any attempts to pan, zoom or use of each interface object.
18.	Complete the overall review section of the questionnaire. Explain that: 'This section concerns the experience as a whole. It may seem like a lot of questions, but it takes between 3-10 minutes to complete. Please try to answer with your first impression.'
19.	Participant is moved away from the table to a chair and desk where they complete the remaining overall exercise review section of the questionnaire checking for missed questions.
20.	Check through the completed questionnaire searching for missed or incomplete questions.
21.	Stop Audio recording.
22.	Thank participant.
23.	Offer selection of thank you mini chocolates or UTAS T-shirts.
24.	Rename Touch Logfile
25.	Paper clip Consent form, Supplementary Information sheets and the Questionnaire together – put in locked cabinet.
26.	Reset the table interface for the next participant.

5.2.1 Avoiding Bias by Changing the Sequence

To avoid any possible bias from a specific combination of worked example and test order the two sets of worked examples and the two tests were designed to be interchangeable. Therefore these could be swapped around. There are 8 unique configurations for Static Map/Interactive Table, worked examples and test combinations (Table 9). These 8 sequences were pre-ordered in a spreadsheet so participants were assigned their sequence based upon the order in which they arrived to undertake the exercise. The spreadsheet contained a group list and an individual list.

Table 9: There are 8 combinations of exercise elements which comprise the unique sequences. Participants were assigned a specific sequence in a preselected random order. An equal number of participants complete each sequence.

Group	1		2		3		4		5		6		7		8	
Static Maps or Interactive Table	S	I	I	S	S	I	I	S	S	I	I	S	S	I	I	S
Worked Example Set Sequence	Ex1	Ex2	Ex1	Ex2	Ex2	Ex1	Ex2	Ex1	Ex1	Ex2	Ex1	Ex2	Ex2	Ex1	Ex2	Ex1
Evaluation Test Sequence	IT	F	IT	F	IT	F	IT	F	F	IT	F	IT	F	IT	F	IT

5.3 The Design of the Response Questionnaire

The participant questionnaire has 47 questions divided into 5 main sections, which include the pre-test, interim test and the final test. The first section is completed prior to pre-test, while the last section contains the review questions completed after the post-test.

The first group of questions (Q1- Q7) concern the participant's predisposition to bushfire. Predisposition may influence engagement or preparedness to learn about bushfire. Asking these questions at the beginning of the questionnaire coerces the participant to think about bushfire and helps to mentally focus their mind upon bushfire.

Q1 What is your postcode?

This questions is asked because postcode shows where participants are from and may be useful for patterns in deeper analysis.

Q2 Do you believe there is a bushfire risk where you live?

☐ Yes

☐ No

Q3 How vulnerable do you feel about the possibility of a bushfire affecting you, your family, or property?

1 - Not at all vulnerable - Highly vulnerable

Q4 How prepared do you feel you are for a potential bushfire event?

1 - Not prepared at all	2	3	4	5 - Highly prepared

Q5 Do you have a written Bushfire Survival Plan?

☐ No ☐ Yes

The questions Q2-Q5 provide an impression of the current preparedness and perceived bushfire risk.

Q6 How well informed do you consider yourself regarding bushfire and bushfire risk?

1 - Not at all	2	3	4	5 - Highly informed

This question is asked because it helps to explain high pre-test scores.

Q7 Do you understand the term Defendable Space with regards to preparing a house for bushfire?

☐ Yes ☐ No

The question is asked because *Defendable Space* is the main theme in the application.

1 - Not at all	2	3	4	5 - Highly informed

The second set of questions are the pre-test which is composed of two parts. The first part asks for recall of facts, while the second is a practical test of three bushfire scenarios. The participants are asked to complete the first part of the test (Q8-Q10), then stop. For the second part, participants are shown photos (on an A4 sheet) of scenarios from Victoria bushfire education, one at a time then subsequently asked questions Q11-Q13 of each. The responses are recorded on the supervisor sheet.

PRE-TEST

Q8 What is the most important task when preparing your property for bushfire?

Comment:

____

Q9 What inner distance should you prepare a defensive zone around your house if you live on relatively flat land in a forested area?

☐	☐	☐	☐	☐
Not sure	10m	20m	35m	Up to your Property boundary

Q10 Tick the zones where the following features ideally should be present: (Features may occur in one, both, or neither zone)

	Inner Zone	Outer Zone
Woodpile	☐	☐
Tall trees without lower limbs	☐	☐
Dam	☐	☐
Vegetable garden	☐	☐
Small trees and shrubs	☐	☐
No trees	☐	☐

Practical Scenarios

Scenario 1

Scenario 2

Scenario 3

Q11 What is the greatest danger to the property?

Q12 What actions do you recommend to prepare this property for bushfire?

Q13 In a severe bushfire event – would you Stay or Leave if you lived here?

These images are from:

http://www.bushfireeducation.vic.edu.au/for-learners/secondary/preparing-for-bushfires/ssec-prepa-act1.html

The next two sections of the questionnaire are the interim test and the post test. They encompass questions Q14-Q25.

The remainder of the questionnaire after the post-test starts with a review of the exercise directly asking about the perception of whether there was belief that anything was learnt from the experience.

Q26 Do you believe that you learnt something about preparing for a bushfire from using the interactive surface with the objects?

☐	☐	☐
No	May be	Yes

This question was asked to qualify if the participant felt they learnt from the experience regardless of whether the tests show they learnt or not.

Q27 Did this experience inspire or motivate you to become more prepared for a bushfire as a result of the experience of using the touch table system?

☐ No ☐ May be ☐ Yes

This question was asked because inspiration and motivation are indicators of adult learning (Knowles et al., 2005).

Q28 If your prior knowledge was sufficient so that you feel you did not learn anything new - do you believe you now have a deeper understanding from this experience of using the touch table system?

☐ N/A ☐ No ☐ May be ☐ Yes

This question is designed to target experts to determine if they gained a learning benefit from the experience. Some may answer No to Q26 because they already had the knowledge so did not learn anything form this experience, yet they may have a deeper understanding of their existing knowledge. This quandary was learned from the Kingston pilot study (Section 4.8.1).

The next set of questions explores the contribution from the components of the interface.

Q29 Consider how each aspect of the experience contributed to your understanding and rate according to the scale in the following table.

Contribution to Understanding

Feature	Not at all	Low level	Reasonably	High level	Essential
The video					
Being able to see the houses in the landscape on the aerial photo					
Using the house, rake and chainsaw to interact with the table					
Being able move around the map					
Seeing the defendable zones on the map					
The size of the display screen					
The examples with Static Maps					
The worked examples on the Interactive Map					
The experience as a whole					
The test questions					
The touch table					

Q30 How beneficial is using recent aerial photography of the local region for the examples?

☐ Not at all ☐ Slightly ☐ Reasonably ☐ Very ☐ Essential

This question links to Domain Specific Context.

Q31 Did the Interactive Map worked examples offer more benefits than the non-Interactive Map worked examples?

☐ Yes ☐ No

This question asks for the direct comparison between the two systems as a check against the results from the analysis. It also provides the perception of the participant regardless of quantitative results.

Q32 Did using the Interactive Table system influence discussion or interplay between group members?

☐ N/A ☐ Yes ☐ Somewhat ☐ No

This question provides quantitative collaboration information.

Q33 What is your impression of using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about *Preparing for Bushfire*?

Comments:____ __

This question gathers target audience thoughts on the broad concept of physical objects as interface elements.

The following three questions are concerned about engagement. The questions are designed to isolate engagement for key individual elements of the interface:

1. Tangible object interaction (Q34),
2. Interactive Mapping (Q35) and,
3. Recent air photography (Q36).

Q34 How engaging was using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?

☐ Not at all ☐ ☐ Reasonably ☐ ☐ Very high

Q35 How engaging was using Interactive Mapping on the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Q36 How engaging was using recent aerial photography of the local region with the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

The next six questions make up the flow index, which is an attempt to quantify the focus, concentration and single-minded intent observed by the users of the tangible interface. The use of Flow was motivated by action research participation at the initial field test of the *Preparing for Bushfire* touch table Tangible User Interface (TUI). It was evident that measuring engagement would not adequately describe and quantify the engrossing behaviour demonstrated by the system users.

The original definition of Flow by Csíkszentmihály 1997) is 'a state in which people are so involved in an activity that nothing else seems to matter'. The Flow Indicator is a set of six questions which quantity the measure of flow as a single number. The Flow Indicator derives from a review of existing applications of Flow from empirical studies (Hoffman & Novak 2009a; Schneider, Jermann & Zufferey 2010; Novak et al. 2000; Zuckerman & Gal-Oz 2013). The reflection paper by (Hoffman & Novak 2009b) compares 22 conceptual and structural models of flow. Detailed review of the empirical studies reveals many flow questions exhibit equivalent meaning or intent. E.g. . 'I feel unimaginative when I use the Web.' (Novak, Hoffman, & Yung, 2000, p29) and 'Using FlowBlocks aroused my imagination' (Zuckerman & Gal-Oz, 2013a, p881). Each flow measure was examined for overall score and individual relevance of each question. Some seemed weak – better suited to yes/no responses than Likert, while others were not relevant with loose connection to the question group.

Ultimately the questions chosen for the indicator focused upon quantifying perceived concentration and oneness from the immersion experience with the subject. As a set, the questions were chosen to define a boundary on the experience. The number of questions was restricted because the overall questionnaire was large and the experiment aim included limiting the user experience including post interview to less than one hour.

Q37 Using physical objects on the touch table was inherently interesting

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q38 Interacting with physical objects on the touch table engaged my imagination

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q39 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I thought about other things I could be doing right now.

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q40 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I was aware of distractions

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q41 When using physical objects on the touch table with the Interactive Mapping with local recent air photography, I was totally absorbed in what I was doing

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q42 To what degree do you believe using models (chainsaw, rake, house) helped focus your attention to the task?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Comments:____

The six questions ultimately chosen for the flow indicator focus on a) the participants' perceived level of concentration and b) their *oneness* or immersion with the subject at hand. Flow was measured according to six key factors – interest, imagination, engrossment, distraction, absorption and attention, presented as easily readable and interpretable percentages. Four of the five flow questions were adapted from Zuckerman & Gal-Oz (2013) use of flow questions collated from empirical studies.

Q43 What aspect of the experience was most memorable?

Comments:____

This question is asked because as noted by Benyon (2010, p.99) 'Experience is concerned with all the qualities of an activity that really pull people in.' The question is an open question because it will elicit a more detailed response than a directed yes/no or Likert question. The responses may aid in future designs of these types of interfaces.

Q44 Would you recommend this system to others?

☐ No ☐ Yes

This question is asked because it links to suitability, fit for purpose and engagement (Sharp et al., 2011).

Q45 How familiar do you consider yourself with touch technology (smart phones, tablets, etc)?

☐ ☐ ☐ ☐ ☐

Not at all Very familiar

This question is asked because it links to usability and possible impact of novelty (Price & Falco, 2011).

Q46 Taking into account your previous answers, please provide additional feedback that you feel may be relevant.

Comments:________________ ____

This question is a catch-all so the participant has an opportunity to add a response they feel should be included; yet do not have an opportunity to include because of the design of the questionnaire.

5.4 Deployment

The system was deployed at locations with a high volume of traffic of adults who potentially have available spare time. The observational experience from the pilot deployment of the general public system at Kingston (Section 4.8.1) indicated Library centers as a better option than shopping centres. Furthermore, museums are traditionally a viable source of general public adults with potential spare time. This study targeted the Launceston LINC and the Launceston Museum and Art Gallery as deployment locations.

5.5 Summary

The detailed implementation procedure allows a full test of the hypothesis by evaluating constructivist map-based tasks against current traditionally available system. The detailed steps allow the exercise to be repeated. The questionnaire and investigator recording form are available in Appendix 9.

Chapter 6: **Results**

'Facts and facts alone, are the foundation of science.'

— Francois Magendie

6.1 Introduction

Using the process described in chapter 5 the exercise was conducted at Launceston LINC and the Launceston Museum and Art Gallery. The analysis and results of the 64 participants are presented here. Any discussion of the results is available in the next chapter (Chapter 7 Interpretation and Discussion).

The first result evaluated is a test for presence of learning to establish if learning occurred. This is followed by measures of learning gains. The subsequent tests evaluate the contribution to learning gain from aspects of the interface including: object usage, test order, prior knowledge, constructivist tasks, and time taken to complete.

These results were applied to a multiple regression model of the contributing factors which identified the factors that statistically affect the learning gain or test score. This shows which factors have a measurable impact and to what degree.

The chapter finishes with results from other interesting factors such as engagement and the comparison of results between groups and individuals.

6.2 *Preparing for Bushfire* for General Public Spaces Exercise

The *Preparing for Bushfire* exercise was conducted in the week of 21st July 2014 at the Launceston LINC, an affiliation of the Launceston Library. The exercise extended to the Launceston Museum and Art Gallery for the 1st August and 2nd of August 2014, at the request of the Museum. The exercise was widely advertised by flyers on bulletin boards, flyers on entrance display boards, on a morning ABC regional radio show and via a short news segment on Southern Cross Nightly news.

User sessions were available for the public to reserve a session time for immediate use or a scheduled timeslot (Figure 46). Each session had a 90 minute allocation, although the average completion time was 42mins (SD=10mins). Participants were permitted to undertake the exercise individually or as a small group. The Kingston experience (Section 4.8.1) suggested that most groups would be couples who lived in the same house. Those who participated received their choice of a University of Tasmania T-Shirt or a selection of mini chocolate bars upon completion of the questionnaire.

Figure 46: Interactive Table in situ at Launceston LINC. The man at the desk behind the table is completing the final stage of the questionnaire.

6.3 Summary of Participants

The *Preparing for Bushfire* exercise was undertaken by 64 adult participants – 26 Female and 38 Male. They comprised 45 individuals, 8 groups of 2 and 1 group of 3. All participants considered themselves local residents living within 80km of the Launceston post office.

6.4 Predisposition to Bushfire Risk

The predisposition to bushfire indicates the overall concern that participants feel about their own risk of bushfire. A positive predisposition may indicate a likelihood of keen interest in knowing more about reducing their bushfire risk, reflecting in their engagement with the system.

In our subjects, the majority did not feel there was a bushfire risk where they lived. They felt slightly vulnerable about the possibility of bushfire with most indicating they felt slightly prepared for a potential bushfire, while only 3% had a written bushfire plan (Table 10). Overall this suggests some concern about bushfire, indicating the topic of *Preparing for Bushfire* should appeal to this audience.

Table 10: Predisposition to bushfire risk.

Questions	Median	Description
How vulnerable do you feel about the possibility of a bushfire affecting you, your family, or property?	2	Slightly Vulnerable
How prepared do you feel you are for a potential bushfire event?	2	Slightly Prepared
	Percentage	
Do you have a written Bushfire Survival Plan?	97%	No
Do you believe there is a bushfire risk where you live?	59%	No

6.5 Perception of Prior Knowledge and Understanding of *Preparing for Bushfire*

Unexpectedly, those with a high perception of prior knowledge of *Preparing for Bushfire* do not score as well in the interim and final tests as those with a lower perceived understanding (Section 6.7.1).

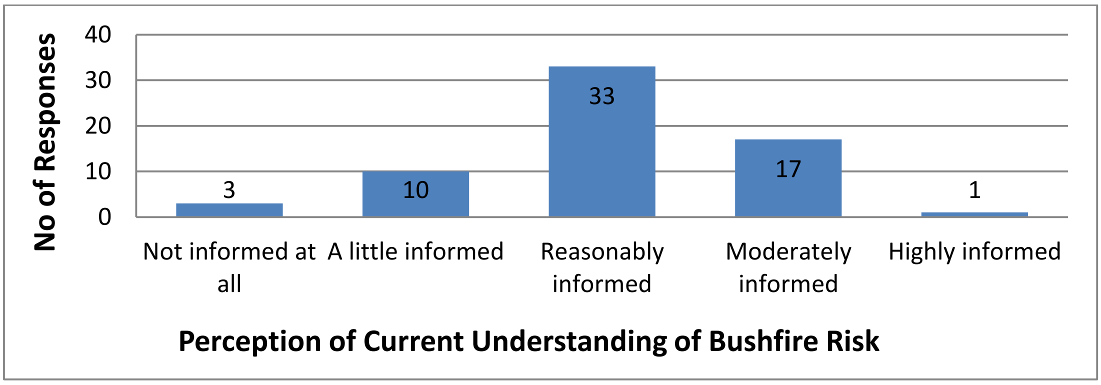


Figure 47: Responses for Q6 How well informed do you consider yourself regarding bushfire and bushfire risk?

More than half the participants felt they were reasonably informed (Median = Reasonably informed) about bushfire and bushfire risk, with another quarter believing they were moderately informed, while only one person believed they were highly informed (Figure 47).

6.6 Test for Presence of Learning

A paired-t test was conducted to determine if the test scores for the pre-test, interim test and post-test were statistically significant. A significant difference indicates that a higher score in successive tests signifies a learning gain occurred. Learning gains potentially occur between each of the tests, subsequently the following three paired-t tests were conducted for both starting conditions (Interactive Table→ Static Map and Static map→Interactive Table):

1. Pre-test and final post-test (overall learning),
2. Pre-test and interim test (interim learning) and
3. Interim test and final post-test ().

The results are summarised below with the results for Interactive Table→Static Map in Table 11 and Static Map→Interactive Table in Table 12. The paired-t tests were calculated using SPSS, which shows Sig. (2-tailed) values of 0.000 - values of 0.000 are equated as 0.001 in this thesis.

In the Interactive Table→Static Map cases the test scores were statistically significant for both initial learning and overall learning ($p < 0.001$)(Table 11). However, the average final score (mean=12.78, SE=0.62) of Interactive Table→Static Map participants was not significantly different ($t(31)=1.2, p=0.236$)) to the average interim test (mean=13.28, SE=0.51), indicating no improvement and therefore no learning gain but also no loss of learning in the Static Map stage.

Table 11: Paired-T statistics comparing test scores for participants starting with Interactive Table session followed by Static Map session.

	Mean	Std. Error Mean	t	Df	Sig. (2-tailed)
Pre-test	7.344	0.3616	-9.078	31	0.000
Post-test	12.781	0.5134			
Pre-test	7.344	0.3616	-9.858	31	0.000
Interim test	13.281	0.6221			
Interim test	13.281	0.6221	1.208	31	0.236
Post-test	12.781	0.5134			

These results are visually represented in Figure 48, where it can be seen that the interim test score and the post-test score are both significantly greater than the initial pre-test test score. The graph also demonstrates the non-significant difference between the interim test score and the post-test score, indicated by the often overlapping red (interim test score) and green (post-test score) lines.

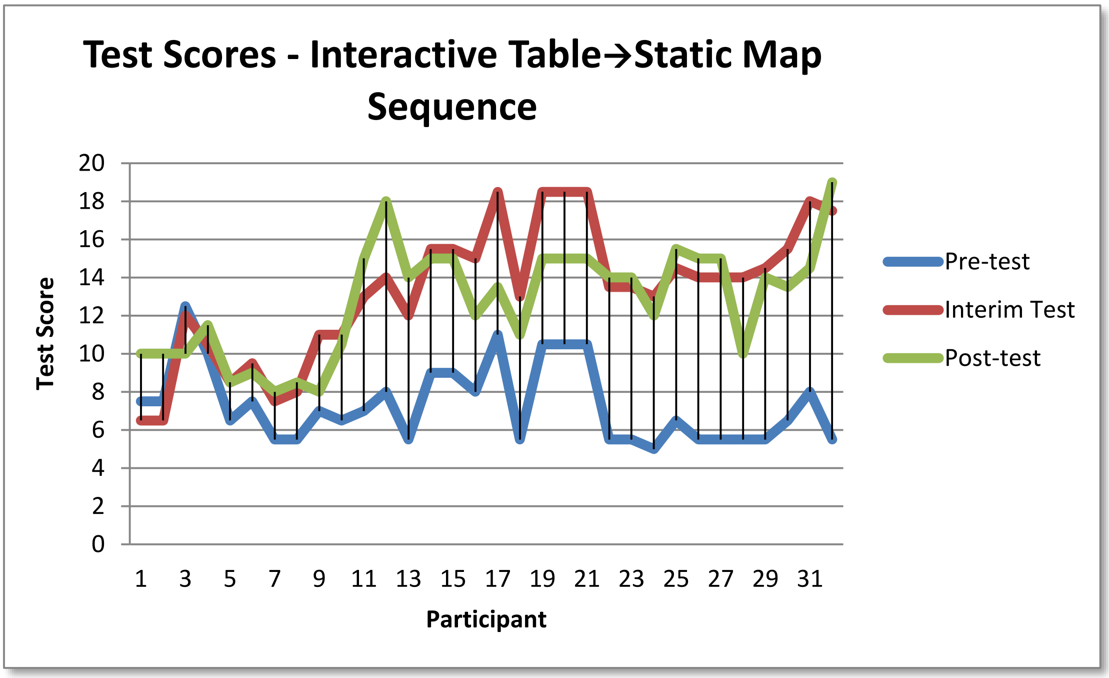


Figure 48: Test scores for participants of the Interactive Table--> Static Map sequence (sorted by pre-test-interim test learning gain) showing the increase in score between the Pre-test and interim test. Note little difference exists between the interim test scores and the post-test scores.

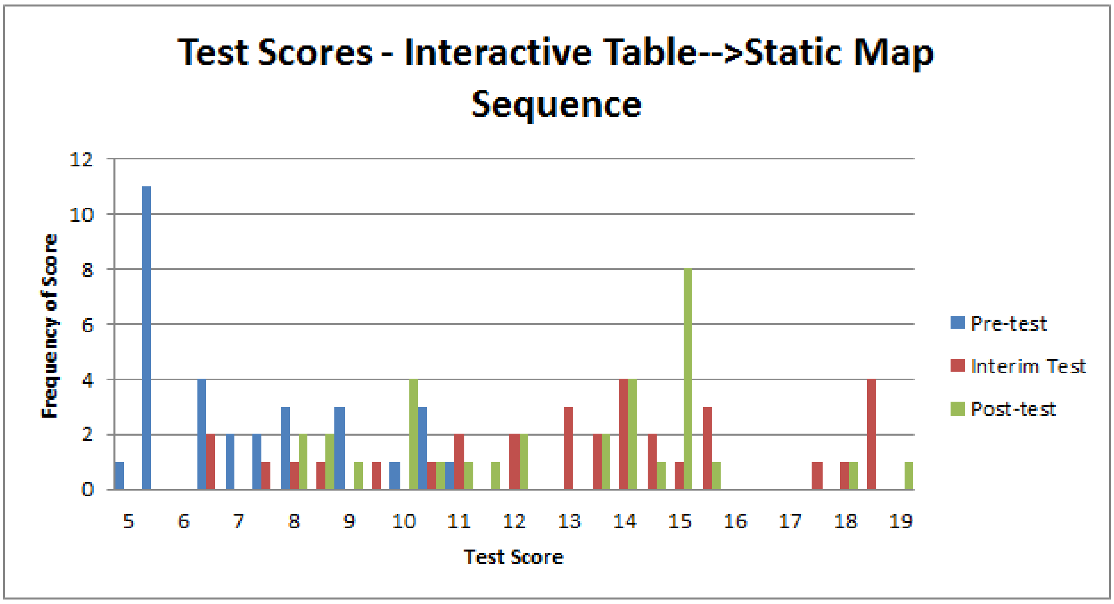


Figure 49: Test scores of the Interactive Table--> Static Map sequence (sorted by pre-test-interim test learning gain).

In the Static Map→Interactive Table cases, the test scores were statistically significant for all three conditions ($p < 0.001$) (Table 12). The difference in the test scores indicates learning gains occurred between the tests at each stage, as well as occurred overall.

Table 12: Paired-T statistics comparing test scores for participants starting with Static Map--> interactive session.

	Mean	Std. Error Mean	t	Df	Sig. (2-tailed)
Pre-test Post-test	7.281 14.047	0.3743 0.5699	-11.695	31	0.000
Pre-test Interim test	7.281 10.422	0.3743 0.4731	-6.431	31	0.000
Interim test Post-test	10.422 14.047	0.4731 0.5699	-6.309	31	0.000

These results are visually represented in Figure 50, where it can be seen that the interim test score and the post-test score are both significantly greater than the initial pre-test test score. The graph also demonstrates the significant difference between the interim test score and the post-test score. A clear separation is seen between the data series visually illustrating the statistical separation of the test scores.

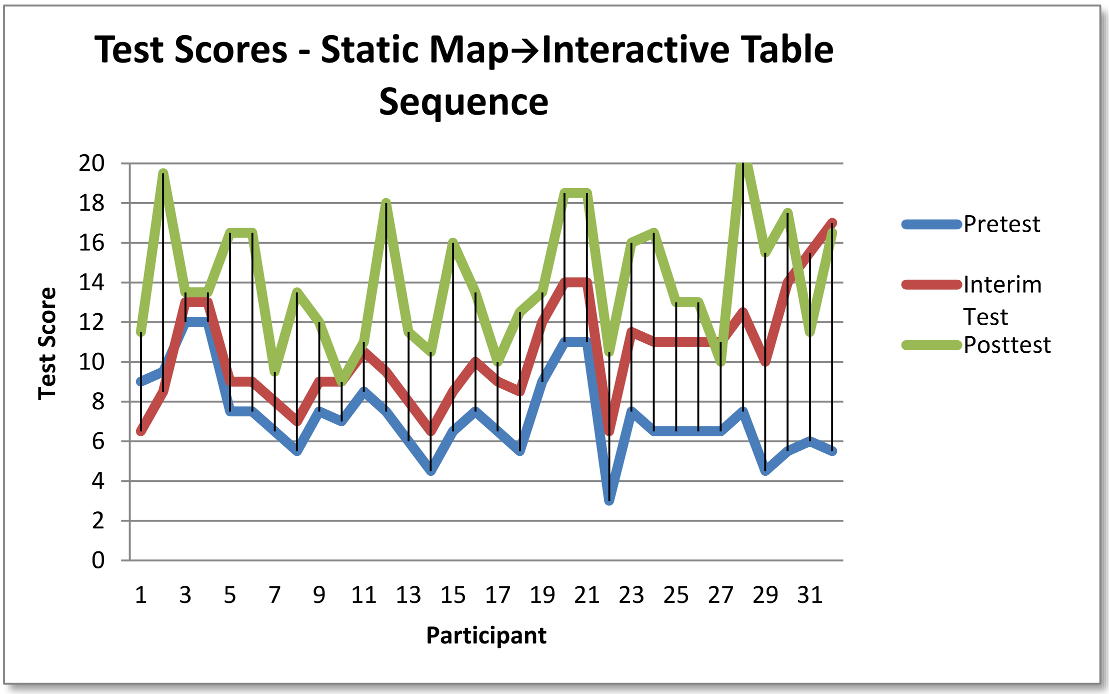


Figure 50: Test scores for participants of the Static Map --> Interactive Table sequence (sorted by pre-test-interim test learning gain) showing the increase in score between the pre-test and interim test. Note also the significant difference between the interim test and the Post-test scores.

6.7 Learning Gains – Change in Understanding of *Preparing for Bushfire*

A positive difference in test scores between tests indicates learning, plus delivers a quantitative value of the learning gain (Howison et al, 2011). The values for learning gain were calculated by subtracting preceding test scores (Table 13).

Table 13: Learning gain improvement in test scores.

Sequence	Pre-test to Interim Test		Interim Test to Post-test		Overall	
	Mean	SD	Mean	SD	Mean	SD
Static map→Interactive Table	2.95	2.84	3.7	3.4	6.66	3.40
Interactive table→Static Map	5.75	3.40	-0.1	2.7	5.64	2.71
Combined	4.35	3.41	1.8	3.6	6.15	3.35

Statistically significant greater pre-test to interim test learning gains ($F(1)=13.01, p<0.001$) occurred with the Interactive Table→Static Map sequence, compared to Static Map→ Interactive Table.

In contrast, statistically significant greater second stage (post-test - interim test) learning gains ($F(1)=33.93, p<0.0001$) occur with Static Map→ Interactive Table compared to the Interactive Table→Static Map sequence.

Although the Static Map→ Interactive Table sequence had the greater overall learning gain, it was not significantly different ($F(1)=2.54, p=0.116$) from the Interactive Table→Static Map learning gain (Table 13). Both methods produce equivalent overall learning gains.

Recapping, the significant learning gain outcomes:

- Tangible Interactive Table sessions provided statistically significant learning gains whether utilised first or second ($p<0.001$),
- Static map sessions only provided significant learning when implemented as the first stage ($p<0.001$),
- Significant overall learning gains occurred using the tangible Interactive Table *Preparing for Bushfire* Interface system regardless of sequence order.

6.7.1 Contribution of the Test Order and Worked Examples

It is possible that test scores were influenced by the worked examples or the order of the tests. This section contains the analysis to determine whether a specific worked example set influenced the results, or whether the order of the tests favoured one method over than another.

To identify any such effects, the 64 participants were randomly assigned to the 8 unique sequences of the exercise, as detailed in Section 5.2.1. These sequences are subgroups within the Interactive Table/Static Map split.

Post-hoc tests (Section 3.5.3.4 and Section 4.8.3) compared these groups for equivalence. No undue influence will be proved if:

1. Static Map→Interactive Table groups have equal learning gain means and
2. Interactive Table→Static Map groups have equal learning gain means.

Table 14: Learning gains improvement in test scores for each unique group sequence.

Sequence	Pre-test to Interim Test		Interim Test to Post-test		Overall	
	Mean	SD	Mean	SD	Mean	SD
Static map→Interactive Table						
1 – Examples Set 1, Test 1	2.69	1.49	4.81	3.22	7.5	3.58
3 – Examples Set 2, Test 1	2.75	2.80	2.19	3.40	4.94	2.78
5 – Examples Set 1, Test 2	2.12	2.55	5.06	3.32	7.19	3.63
7 – Examples Set 2, Test 2	5.00	3.42	2.44	2.43	7.44	2.92
Interactive table→Static Map						
2 - Examples Set 1, Test 1	6.62	2.49	-1.31	2.49	5.31	2.19
4 - Examples Set 2, Test 1	6.12	4.37	-0.50	2.14	5.62	5.38
6 – Examples Set 1, Test 2	4.50	4.23	0.75	2.99	5.25	3.27
8 - Examples Set 2, Test 2	6.50	2.20	-0.94	1.35	5.56	2.50

All odd sequences are Static Map→Interactive Table groups, while all even sequences are Interactive Table→Static Map groups.

Some group means of the sequences of interim test learning gains are significantly different from one another ($F(7,56)=2.80, p<0.05$)(Table 14). Pair-wise comparisons of groups show 6 pairs have significantly different means (Figure 51). The significant pairs are odd to even group sequences. There are no even-even pairs or odd-odd pairs. Thus, all statistical significant differences occurred between Static Map→Interactive Table and Interactive Table→Static Map pairs. Such a result means:

1. the order of the worked examples did not influence interim learning gain and
2. the order of the different tests did not influence interim learning gain.

Group Pairs	Significant Difference
1-8	0.25
2-3	0.25
2-5	0.10
3-8	0.25
4-5	0.25
5-8	0.10

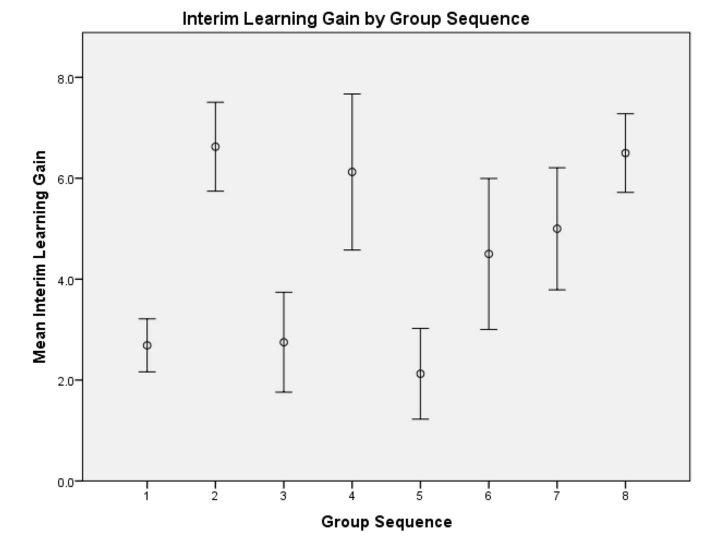


Figure 51: Group pairs of Interim learning gains with significantly different means identified by TukeyHSD (Quinn & Keough 2002). Only Static Map→Interactive Table and Interactive Table→Static Map pairs have different means, indicating that the order of the tests and the order of the examples, does not significantly affect the interim learning gain.

Similarly, group means of the final learning gains are significantly different ($F(7,56)=6.57, p<0.001$). Pair-wise comparisons of groups show multiple groups have significantly different means (Figure 52).

Group Pairs	Significant Difference
1-2	0.05
1-4	0.05
1-8	0.05
5-2	0.05
5-6	0.05
5-8	0.05

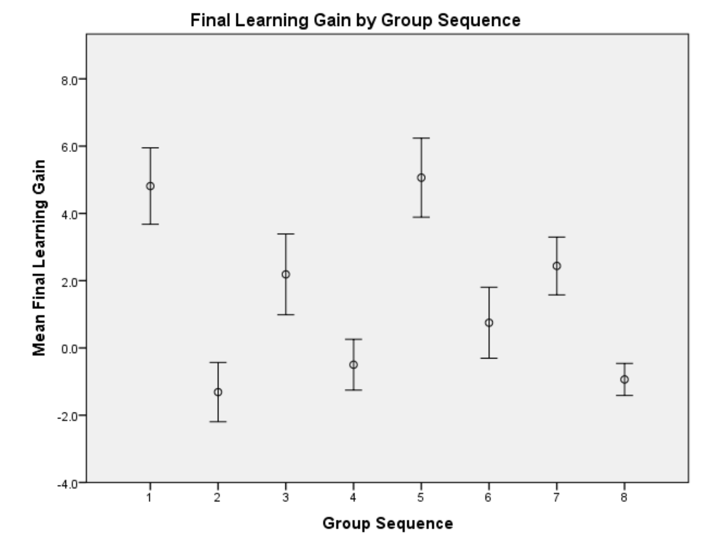


Figure 52: Group pairs of Final learning gains with significantly different means identified by TukeyHSD (Quinn & Keough 2002). Only Static Map→Interactive Table and Interactive Table→Static Map pairs have different means, indicating that the order of the tests, and the order of the examples, does not significantly affect the interim learning gain.

All significant group pairs are odd to even group sequences. There are no even-even pairs or odd-odd pairs. Thus, all statistical significant differences occurred between Static Map→Interactive Table and Interactive Table→Static Map pairs. Such a result means:

1. the order of the worked examples did not influence final learning gain and
2. the order of the different tests did not influence final learning gain.

No significant difference ($F(7,56)=0.80, p=0.59$) exists for the overall learning gains. Although it is apparent that the three greatest overall learning gains (sequences 1, 5 and 7) are from Static Map→ Interactive Table sequences (Table 14). All sequences produce equivalent overall learning gains.

6.8 Contribution from Constructivist Learning Tasks

The constructivist learning tasks (Section 4.8.3) are interactive exercises where each participant may use tangible model objects to interact with the touch table to answer scenario style practical questions. The scenarios may be answered in full without using either the table or the tangible objects, yet every participant used the interface when answering the practical questions.

The tangible tools leave a graphic trail onscreen depicting the intent of changes to better prepare the property for bushfire as observed in Figure 54. The orange patch appears from use of the chainsaw representing selectively clearing trees or removing lower tree limbs. The bright green appears from use of the rake representing cleaning of leaf litter. Interestingly many participants swiped the rake over the house to clean leaf litter from the house gutters, thereby effectively ember proofing the house.

The graphic trails have a measurable area that is georeferenced to the background image as a spatial map layer. Each scenario has an available solution as a georeferenced map layer. This provides the capability to quantify the final answer painted by the tangible objects by comparing the difference between the two spatial map layers using GIS analysis. However, it became obvious early in the general public exercise that the manner in which the participants were using the tangible model objects was indicative rather than exact. The graphics were included for emphasis, or demonstration of the recommended actions, to help clarify the spoken answer to the scenario question.

Furthermore, most participants seemed conditioned for the quick response of capacitive touch, not the slow steady pace of infra-red touch, hence frequently the tangible rake and chainsaw objects were moved faster than the touch detection speed of the touch table resulting in gaps in the intended linework. The qualitative comments verify the struggle with the touch speed. Therefore no GIS analysis of the graphic trails was conducted.

Some participants were very thorough with their use of the tangible tools, almost perfectly matching the ideal answer, while others were minimalist or abstract. Those with highly detailed graphical contributions corresponded with detailed verbal responses resulting in a high score.

Twelve different scenarios were available as either worked examples or practical exercises (Table 6 and Table 7).

6.8.1 Examples of Completed Worked Examples and Practical Exercises

The following five examples show a photo of the interface after the participant has competed the task. The first two are worked examples and the last three are practical exercises. They show the interface at the completion of a worked example or practical exercise. They provide evidence of the use of the tangible model objects during the constructivist tasks, as the graphic trails can only be created with the tangible object tools. These examples are representative of typical use of the object tools. They do not represent the best use of the object tools or the interface.

6.8.1.1 Worked Example Scenario 2

The first example property is a bowls club with well-established gardens and grounds (Figure 53). The participant has indicated that they would clear the vegetation away from either side of the road (shown in orange) to reduce their risk of being trapped, plus to allow access Fire Brigade trucks. They show they would clear the leaf litter and bark from around the main building (shown in green). The house model shows the defendable zones boundaries around the main buildings. The green area does not match the defendable zones (shown as circles with a dashed line boundary) that indicates that this participant likely did not use the house object to depict the defendable zones, instead they estimated the boundaries. Typically adults have poor estimating skills for distance on air photography unless they have been specifically trained (as observed from the author’s personal experience from past air photo interpretation projects).

Figure 53: A community example of a Bowls Club. Note the gaps in the orange lines. The associated audio recording contains a commentary, made simultaneously while using the chainsaw tool, describing the need to clear the vegetation from the roadside of the long driveway.

6.8.1.2 Worked Example Scenario 5

Figure 54: Worked example of a property on the edge of town neighbouring a large native reserve.

The second example (Figure 54) is an urban house neighbouring a large reserve on the edge of town. The participant choose to remove leaf litter on either side of the shared fence line (bright green), plus to remove the lower limbs of the large trees on the property and remove tree limbs close to the house (shown in orange). New town planning laws prohibit this circumstance in the future, however many existing properties are presently in this situation.

6.8.1.3 Practical Example Scenario 2

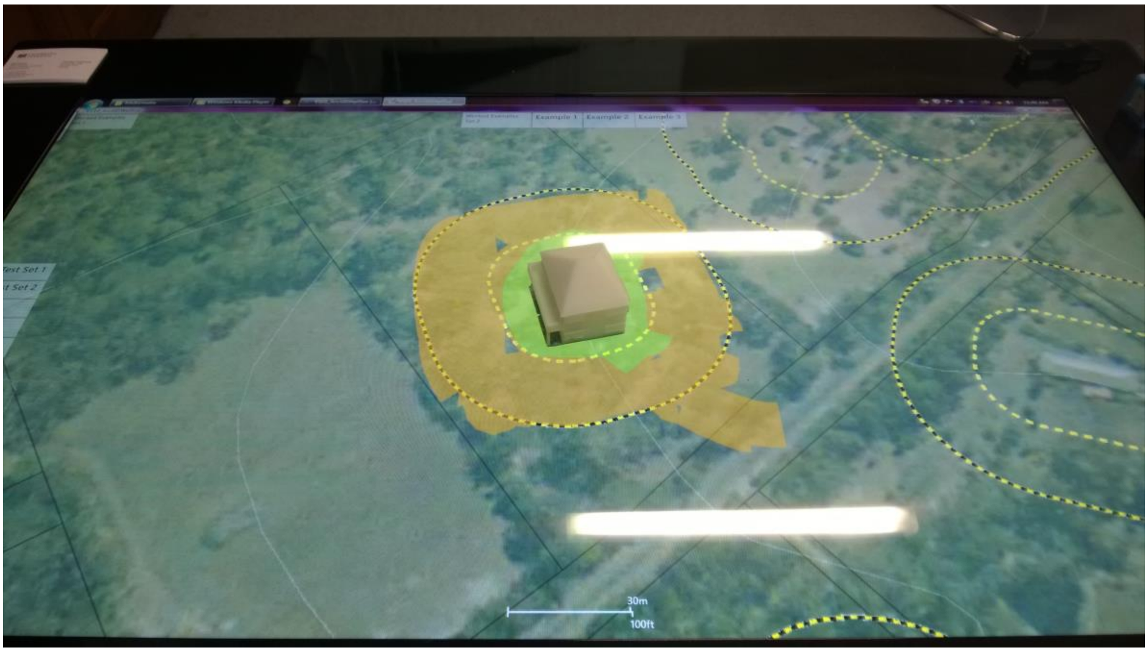


Figure 55: A house surrounded by trees on a standard size block.

The third example is a practical exercise not a worked example. It is a house with a water tank surrounded by trees on a standard sized block (Figure 55). In this case the participant submitted a high scoring answer by:

1. removing the leaf litter surrounding the house (green), selectively clearing the vegetation from the inner defendable space (from audio),
2. ember proofed the home (green shade and supported by audio comments),
3. selectively clearing the vegetation and removing lower limbs from within the outer defendable space (orange and audio),
4. clearing trees from the sides of the driveway (orange) and
5. recommending water tanks, or refill the existing dam (audio).

The crisp alignment of both the orange and green shades indicates that they likely made use of the house object to display the defendable zones.

6.8.1.4 Practical Example Scenario 3

Figure 56: A house on the side of a hill surrounded by trees.

The fourth example is a house on the side of a steep hill with a long winding driveway (Figure 56). The house is surrounded by trees. The participant recommended:

1. to selectively clear the vegetation from the side of the driveway (orange),
2. to remove some trees from immediately around the house, including those touching the roof (orange),
3. to remove leaf litter from the inner defendable space (green),
4. to remove the lower limbs on trees in the outer defendable space (orange). The large diameter of the orange and green shades indicates that this participant remembered that the defendable zones are larger on the side of a hill. Lastly,
5. they acknowledged the need to talk to the neighbour regarding the trees closest to their house (identified by the orange) in the neighbour's property.

6.8.1.5 Practical Example Scenario 4

Figure 57: A house at the bottom of a hill with a tree lined driveway.

The last example is a house at the bottom of a hill with a tree lined driveway (Figure 57). The image by itself is not a comprehensive solution. The participant's answer may have been supplemented by verbal statements, or this may be their complete answer. In this case it was supplemented with verbal statements. The orange swath behind the house correctly identifies that the trees should be selectively cleared and lower limbs removed. The linear orange strip indicates that the trees along the driveway should be pruned and possibly some removed. Only the chainsaw was used. The rake was not used therefore there was no visible recommendation to remove leaf litter from the defendable spaces. The accompanying audio may contain a recommendation to remove leaf litter, but there is no visible indication. The audio descriptions are always a more complete answer than the visual sketches, because they include recommendations that are not represented by interface objects. One such example is water tanks.

6.8.2 Contribution to Test Scores and Learning Gain by the Tangible Objects

This section investigates if the use of tangible objects statistically contributed to the test scores or the learning gains. A linear regression test is performed because the use of objects is hypothesised to directly contribute to an improved test score, hence learning gain.

Object usage may be measured in these variations:

- Frequency of use of each individual interface model object (counts),
- Usage separated into the Worked Examples and the Practical Exercises,
- Length of time spent using model objects and
- Combined total usage of model objects.

The length of time spent using model objects is unable to be determined from usage log files because of the frequent false touches detected by the inherent natures of the PixelSense Sur40 touch table's infra-red touch recognition system – sometimes greater than 1 per second. Video recording of user sessions, with the camera focused upon the screen would have been an effective alternative method of measurement of time spent using model objects. Use of a video camera was deemed as unnecessary compared with logging all touch events. Detailed analysis of the logfiles was overlooked in the pilot stage, at which time logfiles were reviewed for key milestone events.

Consequently, only the frequency of use was available as a user interface measure of model objects. It was decided to choose the combined total frequency of use of all objects in all tasks to test for a correlation relationship with test results.

The regression analysis uses only the 32 participants in the Interactive Table→Static Map sequence for the interim test and uses the 32 participants from the Static Map→ Interactive Table sequence for the Post-test evaluation – as these are the only times objects are used. A summary of the regression results is in Table 15.

Table 15: Regression analysis investigating relationship between frequency of use of tangible interface objects for learning gain and test score. A significant relationship exists for post-test learning gain ($p<0.05$).

	Test Score	Learning Gain
Interim Test	$F(1,30)=4.075$, $R^2=0.1196$, $R^2_{Adjusted}=0.0902$, $p>0.05255$	$F(1,30)=1.6$, $R^2=0.0506$, $R^2_{Adjusted}=0.01898$, $p>0.05$ n.s.
Post-test	$F(1,30)=1.763$, $R^2=0.0555$, $R^2_{Adjusted}=0.02403$, $p=>0.05$ n.s.	$F(1,30)=4.227$, $R^2=0.1235$, $R^2_{Adjusted}=0.09428$, $p<0.05$

A statistical significant relationship is found to exist between the frequency of use of tangible interface objects and post-test learning gain ($p<0.05$).

What is also interesting is the actual p-value of interim test score regression is p=0.05255 (Table 15). Such a marginally significant p-value warrants further investigation of the relationship between *frequency of use of interface objects* and interim test score.

To this end a multiple regression model evaluated the two separate components of the total frequency of tangible interface object used (for Worked Examples and Practical Exercises). Subsequent linear modelling analysis proves the frequency of use of tangible interface objects in the Worked Examples have a significant relationship with the interim test score ($F(1,30)=5.97$, $R^2=0.1666$, $R_{Adjusted}=0.1382, p<0.05$).

The number of times objects used in the interface has a significant effect on the interim test score and the post-test learning gain.

6.8.3 Itemisation of the Overall Time taken to Complete the Exercise

This section reports the time spent in each section of the general public exercise that had potential to contribute to learning (Section 5.2 and Figure 45). These sections encompass:

1. The TFS *Preparing for Bushfire* educational video (4min 3sec video),
2. The first set of worked examples,
3. The three practical exercises of the interim test,
4. The second set of worked examples and
5. The three practical exercises of the post-test

The times are summarised in Table 16, for both sequences; all numbers are in minutes. Both sequences take the same length of time (26.81 minutes and 27.50 minutes respectively.)

Table 16: Time taken (mins) in each section of the general public experiment.

Sequence	1st Set Worked Examples		Interim Practical Test		2nd Set Worked Examples		Post Practical Test	
	Mean (Mins)	SD (Mins)	Mean (Mins)	SD (Mins)	Mean (Mins)	SD (Mins)	Mean (Mins)	SD (Mins)
Static map→Interactive Table	4.78	1.75	6.44	2.75	6.56	2.58	9.03	2.81
Interactive table→Static Map	7.25	2.08	8.94	3.49	5.00	2.05	6.31	2.39

There is less time spent when using the Static Map than the Interactive Table for both worked examples and for the tests regardless of order (Table 17). The Static Map Worked

Examples are completed in 70% of the time taken when using the Interactive Table. Similarly, Practical Tests using the Static Map are completed approximately 70% faster than practical tests using the Interactive Table (Table 17), regardless of order.

Table 17: The time spent on the worked examples and on the tests , grouped by implementation method (all times are in minutes).

Sequence	Worked Example		Practical Test	
	Mean (Mins)	SD (Mins)	Mean (Mins)	SD (Mins)
Static map first	4.78	1.75	6.44	2.75
Static map second	5.00	2.05	6.31	2.39
Interactive table first	7.25	2.08	8.94	3.49
Interactive table second	6.56	2.58	9.03	2.81

6.8.4 Relationship between Tests and Time spent on the Constructivist Tasks

This section investigates the influence time spent on the Interactive Table exercise (the constructivist tasks featuring model objects) statistically contributed to the test scores or the learning gains. A linear regression test is performed because the time spent using the constructivist technique is hypothesised to directly contribute to an improved test score, hence learning gain.

The time may be measured in these variations:

- Length of time spent using each individual interface model,
- Time spent on each exercise task,
- Time spent in total in:
    - the Worked Examples and
    - the Practical Exercises and lastly
- Combined overall *time spent on constructivist tasks*/techniques.

The combined overall time spent on constructivist tasks was chosen as the better representation of the contribution of time to test scores and learning gains. The combined time is the sum of the time spent on the interactive worked examples plus the time spent on the interactive exercises.

The regression analysis uses only the 32 participants in the Interactive Table→Static Map sequence for the interim test and uses the 32 participants from the Static Map→ Interactive Table sequence for the Post-test evaluation. A summary of the regression results is shown in Table 18.

Table 18: Regression analysis investigating relationship between *Time spent on constructivist tasks* and *learning gain and test score*. A significant relationship exists for the interim test for both the test score and learning gain (p<0.01)

	Test Score	Learning Gain
Interim Test	$F(1,30)=21.69$, $R^2=0.4196$, $R^2_{Adjusted}=0.4002$, $p<0.01$	$F(1,30)=8.989$, $R^2=0.2306$, $R^2_{Adjusted}=0.2049$, $p<0.01$
Post-test	$F(1,30)=3.196$, $R^2=0.0963$, $R^2_{Adjusted}=0.0661$, p=>0.05 n.s.	$F(1,30)=1.996$, $R^2=0.0624$, $R^2_{Adjusted}=0.03113$ p>0.05 n.s

The *time spent on constructivist tasks* has a statistically significant relationship with the interim test score and the learning gain from the pre-test to the interim test.

6.9 Contribution of Prior Knowledge to Test Scores

Logically, prior knowledge and understanding of *Preparing for Bushfire* should contribute to test scores for such. The perception of knowledge may be different from their actual knowledge. The spread of test scores shows that the highest scores were present for those who believed they were Reasonably Informed, rather than Moderately Well Informed or Highly Informed (Figure 58).

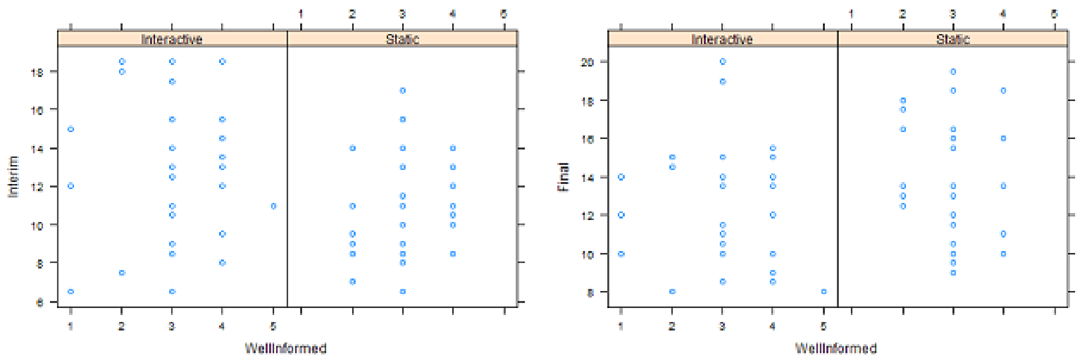


Figure 58: test scores vs participant's perception of understanding of *Preparing for Bushfire* (Well-Informed), with 1 being *Not at all* to 5 being *Highly Informed*

A regression analysis of the interim test shows that there is no correlation between the perception of prior understanding of bushfire and the test scores from the *Preparing for Bushfire* exercise regardless of sequence ($F(1,30)=0.2749$, $R^2=0.01861$, $R_{adjusted}=0.04907$, $p>0.05$ ns).

6.10 Groups Vs Individuals

This section compares the results of participants who completed the exercise in groups compared with participants who undertook the exercise as individuals.

Sequence	Group	Individuals
Interactive Table→Static Map sequence	11	21
Static Map→ Interactive Table	8	24

Figure 59: Distribution of participants between groups and individuals.

The 64 adult participants (26 Female and 38 Males) comprised 45 individuals and 9 groups (8 groups of 2 and 1 group of 3). The members were split evenly between the two sequences (Figure 59)

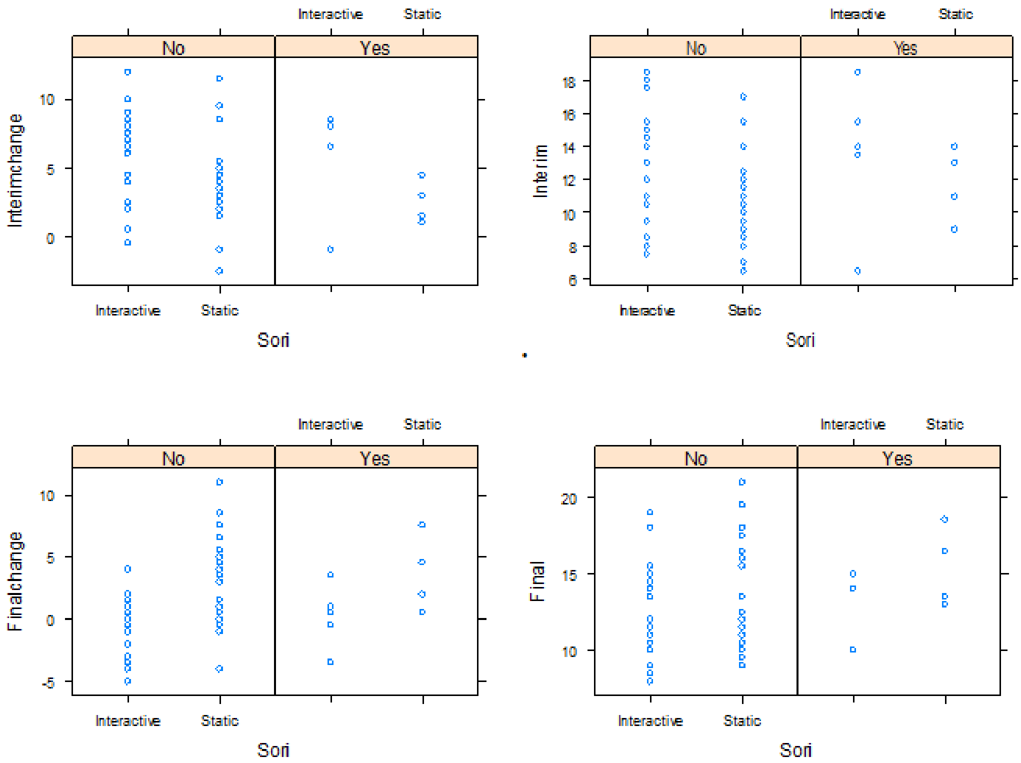


Figure 60: test scores and learning gains for Group members and Individuals. No indicates an individual participant, while Yes indicates a Group member. InterimChange indicates Interim learning gain, Interim indicates interim test score, Finalchange indicates learning gain between interim test and post-test, while Final indicates Post-test test score. The group results mirror the individual results, with a smaller variance.

All group members claimed that the Interactive Table system influenced discussion or interplay between group members during the exercise (79% definite, 21% somewhat).

The test results and learning gains were not significantly different between group members and individual participants for the learning gains between tests (pre-test – Interim: $F(1,62)=0.0199$, $p=0.8883$; Interim test – Post-test: $F(1,62)=0.3582$, $p=0.8656$.)

6.11 Model of Factors Contributing to Test Scores and Learning Gain

This section investigates the impact of each of the contributing factors to the test scores and/or learning gain.

A multiple regression model shows the influence each contributing factor makes to the scores. This is useful because it identifies which factors are significant and how it quantifies the degree each factor contributes to the score.

A test score is the absolute score recorded for a test. The learning gain is described as the difference between two successive test scores, therefore learning gains may occur between:

1. pre-test and final post-test,
2. pre-test and interim test and
3. Interim test and final post-test.

The hypothesis focuses upon the constructivist learning techniques, therefore the model concentrates on constructivist tasks. The constructivist tasks are map-based exercises on the touch table using model objects. The contributing factors are conditions that may influence the outcome of these exercises.

These conditions include:

1. Time taken to complete exercise tasks,
2. Number of times each interface feature is used,
3. Prior knowledge and
4. Number of group members.

However, we already know both Prior Knowledge (Section 6.9) and number of group members (Section 6.10) do not significantly affect test scores. Therefore the model will only use: Time taken to complete exercise tasks and Number of times each interface feature is used.

6.11.1 Multiple Regression Model Assumptions

All multiple regression relies on the following assumptions (Quinn & Keough 2002): Outliers removed, collinearity of data, independent errors, random normal distribution of errors, homoscedasticity & linearity of data and non-zero variances.

A review of the standard residuals of the *Frequency of use of interface object*s and *Time spent on constructivist tasks* showed that data contained no outliers (Std. Residual Min=-1.70, Std. Residual Max = 2.79).

Collinearity statistics indicated that multicollinearity was not a concern (*Frequency of use of interface objects*, Tolerance = 1.0, *VIF* = 1.0; *Time spent on constructivist tasks*, Tolerance = 1.0, *VIF* = 1.0). Tolerances approaching 0 indicate a multicollinearity problem, while VIF states the factor by which the sample size must be increased to eliminate multicollinearity (Quinn & Keough 2002).

The data met the assumption of independent errors (Durbin-Watson value = 2.315).

A histogram of standardised residuals indicated that the data contained approximately normally distributed errors, as did the normal P-P plot of standardised residuals, which showed points that were not completely on the line, but close. The scatterplot of standardised predicted values showed that the data met the assumptions of homogeneity of variance and linearity.

The data also met the assumption of non-zero variances (*Frequency of use of interface objects*, Variance = 207; *Time spent on constructivist tasks*, Variance = 20.5; interim test score, Variance = 12.4; interim learning gain, Variance=11.61).

A multiple regression model was created since the assumptions for the data were met.

6.11.2 Model Results

The regression model uses all 32 participants from the Interactive Table→Static Map sequence for the interim test and uses all 32 participants from the Static Map→ Interactive Table sequence for the Post-test evaluation. A summary of the multiple regression analysis shows *Frequency of use of interface objects* and *Time spent on constructivist tasks* directly influence both the interim test score and interim learning gain (Table 19).

Table 19: Multiple Regression Analysis investigating relationship between both *Time spent on constructivist tasks* and *Frequency of use of interface objects* to *learning gain and test score*. A significant relationship exists for the interim test for both the test score and learning gain (p<0.01)

	Test Score	**Learning Gain**
Interim Test	$F(2, 29) = 17.5$, $R^2=0.547$, $R_{Adjusted}=0.4907$, $p < .001$	$F(2,29)= 5.90$, $R^2=0.289$, $R^2_{Adjusted}=0.240$, $p<0.01$
Post-test	$F(2,29)= 2.458$, $R^2=0.1449$, $R^2_{Adjusted}=0.08597$, $p=0.1033$ n.s.	$F(2,29)= 3.133$, $R^2=0.1777$, $R^2_{Adjusted}=0.1209$, $p=0.0586$ n.s

Both *Frequency of use of interface objects* and *Time spent on constructivist tasks* explain a significant amount of the interim test score ($F(2, 29) = 17.5$, $p < .001$, $R^2=0.547$, $R_{Adjusted}=0.04907$).

The analysis shows that *Frequency of use of interface objects* significantly predicts the value of interim test score (Beta = 0.357, $t(29) = 2.86$, $p<0.01$), likewise *Time spent on constructivist tasks* significantly predicts the value of interim test score (Beta = 0.654 $t(29) = 5.23$, $p < .001$).

Frequency of use of interface objects and *Time spent on constructivist tasks* explain 54.7% of the variance of the interim test score. The *Frequency of use of interface objects* explains 12.35% while the *Time spent on constructivist tasks* explains 42.36%

Based upon the multiple regression analysis, the interim test score is estimated by:

Interim Test Score = 2.658 + 0.087 Frequency of use of interface objects
+0.508 Time spent on constructivist tasks

Both *Frequency of use of interface objects* and *Time spent on constructivist tasks* explain a significant amount of the Interim Learning gain ($F(2,29)= 5.90$, $R2=0.289$, $R2Adjusted=0.240$, $p<0.01$).

The analysis shows that *Frequency of use of interface objects* significantly predicts the value of interim learning gain ($Beta=0.605$, $t(29)=2.37, p<0.01$), however *Time spent on constructivist tasks* does not significantly predict the value of interim learning gain ($Beta=-0.088, t(29)=-0.346, p=0.08$ n.s.).

Frequency of use of interface objects and *Time spent on constructivist tasks* explain 28.9% of the variance of the interim learning gain, all explained by the *Frequency of use of interface objects*.

Based upon the multiple regression analysis, the interim learning gain is estimated by:

interim learning gain = 1.437 + 0.59 Frequency of use of interface objects

-0.088 Time spent on constructivist tasks

Significant scores for interim test score and interim learning gain are expected because *Time spent on constructivist tasks* is significant only for interim results (Section 6.8.4).

6.12 Perception of Occurrence of Learning

The Q27 question provided the user perception of their own learning as a direct consequence of using the tangible Interactive Table *Preparing for Bushfire* Interface - without knowing their test scores. This is useful because it applies linkages to known adult leaning practices (Section 2.3.3) providing an indication of occurrence and depth of adult learning.

As a direct consequence of using the tangible Interactive Table *Preparing for Bushfire* Interface:

- 100% believe they learnt something about preparing for a bushfire (94% definitely, 6% may be),
- 98% felt inspired or motivated to become more prepared for a bushfire (70% definitely, 28% may be) and
- 87% believe they now have a deeper understanding from this experience (87% definitely, 13% may be) (38 participants answered this question).

6.13 Perceived Contribution to Understanding from Features of the Interface

The participants believed that most aspects of the exercise contributed to understanding to a high level, with three exceptions: *Seeing the defendable zones on the map* (Median=Essential, Mean=4.39, sd=0.68), *the examples with Static Maps* (Median=Reasonable, Mean=3.38, sd=0.77) and *the test questions* (Median=Reasonable, Mean=3.63, sd=0.86)(Table 20). However, it should be noted that *using the house, rake and chainsaw* had the second-highest level of “Not at all + Low level”.

This information provides insight into user preferences and to some degree insight into preferred learning styles as discussed in Section 2.3.3.

Table 20: The perception of the contribution that each aspect of the experience made to understanding. The median is shaded.

Feature	Not at all	Low level	Reasonably	High level	Essential
The training video	0.0%	4.7%	32.8%	35.9%	26.6%
Being able to see the houses in the landscape on the aerial photo	0.0%	0.0%	15.6%	57.8%	26.6%
Using the house, rake and chainsaw to interact with the table	0.0%	10.9%	34.4%	39.1%	15.6%
Being able move around the map	0.0%	0.0%	29.7%	51.6%	18.8%
Seeing the defendable zones on the map	0.0%	1.6%	6.3%	42.2%	48.4%
The size of the display screen	1.6%	1.6%	26.6%	57.8%	12.5%
The examples with Static Maps	1.6%	9.4%	42.2%	43.8%	3.1%
The worked examples on the Interactive Map	0.0%	0.0%	20.3%	50.0%	29.7%
The experience as a whole	0.0%	0.0%	6.3%	62.5%	31.3%
The test questions	0.0%	6.3%	43.8%	31.3%	18.8%
The touch table	0.0%	0.0%	21.9%	51.6%	26.6%

6.14 Engagement and Flow

The design of the engagement measures from three questions (Q34, Q35, Q36) stratifies the experience, enabling delineation of the engagement as extra interface elements are included, changing the emphasis so the original elements are perceived as more integrated rather than the primary focus.

The data in context was very highly engaging, both in the context of the application of the data and the currency of the information. The constructivist tasks using tangible objects along were highly engaging (Table 21).

Table 21: Engagement of the table interface features.

Summary of Engagement	Median	sd	Level of Engagement
How engaging was using recent aerial photography of the local region with the touch table to learn about Preparing for Bushfire?	5	0.69	Very Highly
How engaging was using Interactive Mapping on the touch table to learn about Preparing for Bushfire?	5	0.68	Very Highly
How engaging was using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?	4	0.92	Highly

Flow is a concentrated measure of engagement that quantifies how engrossed participants are in the interface. The Flow Index described in Section 5.3 measures attention focus and cognitive enjoyment. The Flow Index (mean=22.86, sd=3.87, Range=12-28) had a Cronbach Alpha of 0.81 which is deemed acceptable (Sauro & Lewis 2012a). In layman's terms, this means the flow index equates to an overall value of *Agree* that flow is present, given all questions used a Likert scale from Strongly Disagree to Strongly Agree (some reversed).

6.15 Benefits of Map-based Traits of the Interface

The questionnaire asked two clear questions about the perceived benefits of map-based aspects of the Tangible Touch Table Interface for *Preparing for Bushfire* in order to delineate the degree of contribution of recent aerial photography and the application method (traditional vs interactive). These questions are described in Section 5.3.

Tangible Interactive Mapping offers more benefits than traditional methods, furthermore the most benefit is achieved by using recent aerial photography (Table 22).

Table 22: Contribution of the Interface Map-based traits.

Questions	Median	Description
How beneficial is using recent aerial photography of the local region for the examples?	5	Essential
	Percentage	
Did the Interactive Map worked examples offer more benefits than the non-Interactive Map worked examples?	100%	Yes

6.16 Familiarity with Touch

The participants were very comfortable with touch and gesture (Median=5 –Very Familiar, sd=1.06). Only one person had no previous experience with a touch smartphone, tablet, or touch computer, however they had prior exposure with touch panel controls for monitoring equipment so considered themselves a-little-familiar with touch.

6.17 Summary

The general public implementation of the tangible Interactive Mapping table encouraged understanding of *Preparing for Bushfire*. The 64 participants demonstrated improvement in their understanding of the subject ($p<0.001$, Section 6.6). It performed better than current traditional methods for the pre-test to interim test ($p<0.001$, Section 6.7).

The improved understanding (learning gain) is correlated to factors of constructivist learning tasks (practical application of knowledge in test scenarios using physical models that work with Interactive Mapping of locally relevant domain specific context suitable spatial datasets)($p<0.01$, Section 6.11.2):

1. *Frequency of use of interface objects*
   (Beta=0.605, $t(29)=2.37$,$p<0.01$), and
2. *Time spent on constructivist learning tasks*
   (Beta=-0.088,$t(29)=-0.346$,$p=0.08$n.s.).

Frequency of use of interface objects and *Time spent on constructivist tasks* explain 28.9% of the variance of the interim learning gain, all explained by the *Frequency of use of interface objects*.

The analysis shows that *Frequency of use of interface objects* significantly predicts the value of interim test score ($p<0.01$, Section 6.11.2):

1. *Frequency of use of interface objects*
   (Beta=0.357,$t(29)=2.86$,$p<0.01$) and
2. *Time spent on constructivist learning tasks*
   (Beta=0.654,$t(29)=5.23$,$p<0.001$).

Frequency of use of interface objects and *Time spent on constructivist tasks* explain 54.7% of the variance of the interim test score. The *Frequency of use of interface objects* explains 12.35% while the *Time spent on constructivist tasks* explains 42.36%.

This result directly contributes to the hypothesis *A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources*, by addressing the following sections: tangible multi-touch table interface, map-based constructivist learning techniques and encourages understanding of natural resources.

Furthermore the participants experienced a very high level of engagement (Section 6.14) with the interface, which contributed to the belief, of 100% of participants that they learnt from the experience (Section 6.12). Participants reported map-based context as an essential component of the system – a system which 100% would recommend to others.

Incidentally, participants in groups received the same level of learning gains and test scores as individuals (Section 6.10), while participants' perception of their prior knowledge had no effect on the final test scores (Section 6.9).

The implications of these results is discussed in the next chapter.

Chapter 7: **Interpretation and Discussion**

'I cannot begin to tell you the things I discovered while I was looking for something else.'
— Shelby Foote

7.1 Introduction

The previous chapter presented the results of the general public exercise. This included the contribution to learning gain and test scores from contributing factors of the tangible interface and aspects of the constructivist map-based exercise.

This chapter explains the meaning of the results to the research hypothesis and presents the answer to the research question.

This chapter begins by focusing upon the statistical evidence of presence of learning, examining the method for the highest learning gain, then reviews causes of *encouragement of understanding* with regard to tangible map-based constructivist learning techniques. Other contributing factors of the interface are argued regarding their contribution to learning gain. All the evidence is discussed in context with congruent literature, highlighting differences. After which, the answer to the research question is presented. Limitations in the study are explored, followed by avenues for future work.

7.2 Hypothesis and Theoretical Framework

The overarching goal of the study is to evaluate and identify methods that use new and emerging technology to improve the general public's understanding of the complex nature of natural resources. It does this by using real world data in a real world circumstance that has a high potential direct effect on adults. The circumstance in the thesis is preparing a property for bushfire. The emerging technology is using tangible model objects on a multi-touch table, the evaluation comparison applies a within subjects methodology to the closest suited traditional education technique (printed map examples) (Section 4.10).

The goal is attained by answering the Hypothesis:

H1: A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources

2. What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?

The research method is based upon the theoretical frameworks of:

- Constructivist learning [spatial reasoning/reflection/collaborative interaction]
- Cognitive load theory and
- Domain Specific Context

7.3 Overview of the Significant Finds of the Study

The tangible Interactive Table *Preparing for Bushfire* Interface system encourages learning (see below) by engaging the general public to undertake interactive problem solving tasks using context purpose-designed model objects on a touch table displaying local landscape map images, property boundaries and contours. The model objects (house, chainsaw and rake) fully integrate with the visuals on the display providing immediate feedback as part of a seamless natural interface (Section 4.8.4).

The thesis hypothesis is supported because a meaningful sample size pool (Guest et al. 2006) of 64 adult members of the general public scored higher in subsequent knowledge tests ($p<0.001$(Section 6.6)), thus improving their understanding of *Preparing for Bushfire* – a specific application of the complex interaction of natural resources (Section 4.3).

The improved understanding (learning gain) is correlated to factors of map-based constructivist learning tasks ($p<0.01$), specifically:

1. Frequency of interface tangible object use (Beta=0.357,$t(29)=2.86$,$p<0.01$) and
2. Time spent on constructivist learning tasks (Beta=0.654,$t(29)=5.23$,$p<0.001$).

The learning method is appropriate because learning also occurs using traditional map-based teaching methods employing an identical teaching framework as the tangible interactive interface on the touch table, using the same subject pool. Although, the tangible Interactive Table *Preparing for Bushfire* Interface system performed significantly better than current traditional methods ($p<0.001$)(Section 6.7).

Other contributions to the pool of knowledge include:

- participants in groups received the same level of learning gains and test scores as individuals (Section 6.10),
- perception of prior knowledge has no correlated effect on final test scores (Section 6.9),
- 100% of participants believe they learnt from the experience (Section 6.12),
- participants experienced a Very High level of engagement (Section 6.14) and
- participants reported map-based context as an essential part of the system (Section 6.15).

7.4 Exploring Encouragement of Understanding

The outcome from the general public exercise clearly supports our hypothesis (H1), yet does not explain why it is so. This section explains the results.

7.4.1 Test for Presence of Learning

The test for presence of learning gain is required to statistically prove the hypothesis. Learning is implied during the results, but this test (Section 6.6) verifies unequivocally that learning gain occurs ($p< 0.001$).

7.4.2 Highest Learning Gain

The overall learning gain is equivalent when both systems are used regardless of order (Section 6.7), hence order is not important. The initial learning gain from either method shows statistically significant learning occurs ($p<0.001$).

However, the initial learning gains are significantly greater when using the tangible interactive touch table first than using the Static map traditional method first ($p<0.001$) (Section 6.6). In fact, the difference is so great that the initial learning gain from the tangible Interactive Table *Preparing for Bushfire* Interface is equivalent to the overall learning gain from using the Static Map session followed by the Interactive Table session (Static Map→Interactive Table) (Figure 61).

Figure 61: Learning Gain broken down by contribution from methods.

The entire effective learning for the Interactive Table →Static Map sequence occurs in the first stage (Table 11, $p<0.001$). No effective learning gain at all occurs during the second stage -Static Map phase ($p=0.236$ n.s.) - although no loss of learning occurs either. Therefore the initial learning from the interactive table alone is equivalent to the overall learning as observed in Figure 62. There is no benefit to undertaking the Static Map stage after the tangible Interactive Table interface.

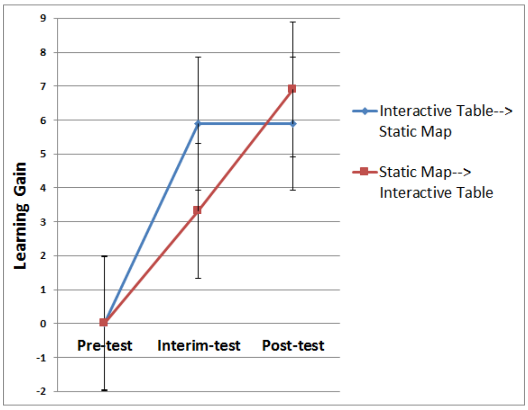


Figure 62: Learning gains between the tests. The interim-test gain is greater for the Interactive Table→Static Map participants, than the Static map→Interactive Table participants. Conversely, the learning gain is greater in the second stage for the Static Map→Interactive Table participants.

The Static Map→Interactive Map sequence has a positive learning outcome from two stage scaffolded learning where positive significant learning occurs in both sections (Table 12)($p<0.001$). However, the two stage process has no learning improvement over an Interactive Table only session ($p=0.116$ n.s., Section 6.7).

Many empirical studies compare TUI to other systems. The following studies are the closest to the *Preparing for Bushfire* exercise (Kirk et al. 2009; Lucchi et al. 2010; Price et al. 2008, Schneider et al. 2013; Streng et al. 2009;) and (Speelpenning et al. 2011).

Of these, the closest work is the neuroscience study from the Learning Sciences and Technology program at Stanford University by Schneider et al. (2013) who investigates the capability of a multi-touch table tangible interface of a neurological simulation to teach adult students fundamentals of neuroscience. The experiment shares several common traits with the *Preparing for Bushfire* system, whilst - not surprisingly – finding similar learning gain outcomes. The Schneider experiment is directly compared to the *Preparing for Bushfire* system in Table 23.

Table 23: Comparison between *Preparing for Bushfire* exercise and the most similar study - Preparing for Future Learning with a Tangible User Interface: The Case of Neuroscience (Schneider et al, 2013).

	Preparing for Bushfire General Public Exercise	Neuroscience Tangible User Learning Interface: (Schneider et al. 2013)
	Common factors	
Research Method	Within Subjects	
Testing	Pre-test – interim test – Post test	
Outcome	TUI produces greatest learning gain	
Participants	Adults	
Tangible object design	High fidelity, high representational value	
Post questionnaire	Question regarding perception of knowledge.	
Differences		
Participants	64 General Public Adults	28 Graduate Student Adults
	No remuneration	Paid
	Groups and Individuals	Groups only
Education Level	Assorted	Post Graduate minimum
Prior knowledge	Evenly distributed (Section 5.5)	Screened for NO prior knowledge
Comparison	MT TUI vs Static Map	MT TUI vs Text book
Topic	Preparing for Bushfire	Neuroscience

Learning method	Task based - Constructivist	Explorative - Preparing for Future Learning (PFL) framework.
Information Presentation Method	Interactive real world mapping (Air photos, property boundaries, topography)	Interactive Simulation showing effects from brain-section objects placed upon the table.
Object – virtual interaction/coupling	1. Chainsaw, Rake & House: Visual digital information augmented by moving tangible object tools. 2. House – two fold by also being a 3rd physical dimension for virtual houses in the map images.	Augmented tangible objects with digital information
Touch Table	Microsoft PixelSense – commercially available	Custom built low cost table
Post questionnaire	50 questions	Few questions

Whilst similar at first glance, there are numerous differences from the topic to the object interface interactions.

The Schneider study possibly has a cleaner measure for learning gains because all their participants were filtered to have no prior understanding of the topic. This removes the noise present in the pre-existing knowledge level of the general public. The knowledge level of the general public is a fuzzy variable. Each member will always have a slightly different degree of understanding about any topic than other members of the general public. Not filtering on prior knowledge is a more realistic evaluation of the system.

The object interaction with the table in both systems is coupled with a virtual visual response, however they differ in the manner in which the objects are used. Objects are placed in Schneider et al's study, while only the house in placed in the *Preparing for Bushfire* system. In the *Preparing for Bushfire* system the rake and chainsaw were designed to actively move in a manner simulating real life manipulation of models that resemble everyday objects.

The Schneider (2013) paper does not compare their work to other TUI papers rather it focuses their comparison to other systems that attempt to teach neuroscience, avoiding the need to compare to other potential learning TUI.

Schneider et al. (2013, p.127) are careful to qualify the results:

> Obviously, our results do not indicate that TUIs are a panacea for all disciplines; however, they show that the TUI and PFL combination may work particularly well for certain learning contexts.

This statement implies the combination of TUI and Preparing for Future Learning (PFL) framework benefit learning. Furthermore, because this combination works, then there is credence to expand research to include TUI with constructivist task. This inclusion indicates that Schneider et al recommend other teaching paradigms should be evaluated when combined with TUI. The *Preparing for Bushfire* system meets this recommendation by combining constructivist tasks with TUI for learning goals.

The highest learning gain is achieved from using the tangible Interactive table session by itself. It will be the quickest and provide the highest learning gain.

7.4.2.1 Low learning gain aberration

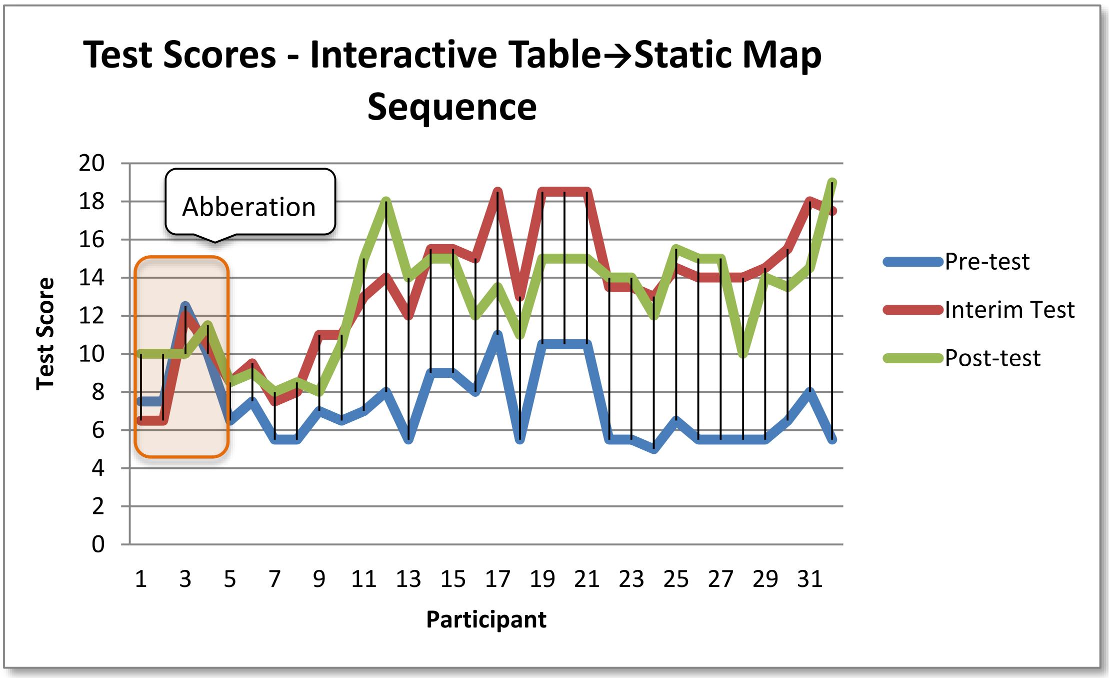


Figure 63: Test scores for participants of the Interactive Table--> Static Map sequence (sorted by pre-test-interim test learning gain). The highlighted aberration shows participants with negative or zero interim learning gain.

An apparent anomaly is noticeable when the test scores are shown in order of interim learning gain (Figure 63). The first sets of points on the left hand side of the graph are participants with almost no learning gain (variance:-1 - 2). Investigating these participants for common similarities determines if a possible failure point exists of the system. Brief review of the first 4 participants (participant id 4, 5, 6 and 42 respectively) shows: the first two are partners the same group, while the 3rd and 4th scored the two highest pre-test scores. Individual investigation of their questionnaires, log files and recorded audio from their sessions; shows:

Participants 1 &2:	Review of the session audio exposes that both participants are from regions of their separate home counties where bushfire is a not an issue. They have no past experience with the concept and actively discuss how bushfire would not have a place in their future. This impact from an adult learning perspective is explained by Knowles et al. (2005, p.67) with 'Adults are motivated to learn to the extent that they perceive that learning will help them perform tasks or deal with problems that they confront in their life situations.' Therefore the participant's low personal experience and low perceived future purpose imply they will have little interest in learning about bushfire, hence their low learning gain.
Participant 3:	Review of the audio tells how this participant recently started work with the Tasmanian Fire Department. They believe themselves to have a solid grasp of the fundamentals, but both need and want to learn more about fire behaviour within a variety of environmental situations. They were reserved and qualified for many of their responses. Although they had no learning gain, their interim test score was in the median.
Participant 4:	Review of comments from the audio log show this participant lives in a rural setting on a bush block. They actively apply methods to prepare their property for bushfire. They know the risks and mitigation strategies for their own circumstances very well. They did seem to struggle when applying the theory to other situations, but scored well when answering practical exercises similar to

> their own circumstances – 'This is like my place'. Such behaviour is a typical trait of motivation for adult learning. 'Adults tend to be more motivated toward learning that helps them solve problems in their lives' (Knowles et al. 2005, p.199).

The low learning gain for the first four ranked participants is expected when the individual participants are examined (above), so they are not an indication of a gap or flaw in the system.

7.4.3 Contribution from Map-based Constructivist Learning Tasks

The tasks are carefully designed to appeal to multiple adult learning traits (Section 4.9 Design of Map-based Constructivist Exercises using Tangible Objects) including the following assumption (one of five) that underlies the Andragogical model of learning Knowles et al. (2005, p.67):

> Adults are motivated to learn after they experience a need in their life situation. For that reason, learning needs to be problem-focused or task-centered. Adults want to apply what they have learned as quickly as possible. Learning activities need to be clearly relevant to the needs of the adult.

The tasks are designed as two groups of three increasingly harder problems (problem-focused or task-centered) that directly relate to people who live locally in a rural residential region. The tasks are designed to prompt the users to take action beyond the desktop.

The optimal design basis means the expectation is that adults will be attracted to, then engaged by the tasks, after which they should be inspired and motivated to act to better prepare their property for bushfire.

How did the tasks perform? The design guidelines held true. The positive Flow index score (mean = Agree (Section 6.14)) verifies the tasks were deemed engaging. Finally, 98% of participants felt inspired or motivated to become more prepared for a bushfire (Section 6.12).

The learning aspect of the interface was supporting of the Tasmanian Fire Service goal of inspiring action. Obviously an understanding of how to prepare for bushfire is important. Yet, the problem space is the lack of progress or impetus from those who have the knowledge or sufficient understanding of the requirements (Mackie et al. 2013). Across Australia there is a low uptake of implementing *Preparing for Bushfire* mitigation actions (Mackie et al. 2013).

The tangible Interactive Table *Preparing for Bushfire* interface has the capacity/functionality to appeal to these people (participants) because it presents the information they know in a different format than they are likely to have seen. The map-based format is well suited to present information about landscapes, environment and people within the sphere of influence. As Knowles et al, (2011, p. 294) states:

> Adults are ready to learn when they perceive a need to know or do something in order to perform more effectively in some aspect of their lives. Their readiness to learn may be stimulated by helping them to assess the gaps between where they are now and where they want and need to be.

The map-based tasks further involve the participants within the new presentation method, empowering manipulation and modification (through the tools), to evaluate cause and effects (Section 4.8.3). This involvement triggered responses such as 'An interesting idea that certainly provoked thought. Bushfire presentation was not previously on my radar but it made me think about our own home situation.' by Launceston General Public participant #10.

The results show map-based constructivist learning tasks seem to have a positive effect on the participants, both for learning and for motivation to apply their *Preparing for Bushfire* knowledge.

The following subsections review leaning gain contributing factors of the map-based tasks focusing on tangible objects, time on task, and cognitive load.

7.4.3.1 Cognitive load

The object interaction with the table is coupled with a virtual visual response. The rake and chainsaw were designed to actively move in a manner simulating real life manipulation of models that resemble everyday objects (chainsaw and rake).

The object design explicitly takes advantage of user's past experiences thereby freeing up mental resources to focus upon problem solving (Price et al. 2008; Zhang & Norman 1994). This movement was effective, at-least according to Launceston General Public Participant #24 who commented 'This is quite natural. I like that. That's clever.'

The chainsaw and rake object manipulation is a well-practiced movement commonly associated with chainsaws and rakes. Such interface actions should minimise cognitive load (Oviatt 2006). The Oviatt (2006) study showed significantly better results when using a very familiar and well understood tangible object with a touch interface (stylus with tablet), than with touch interface alone. Similar to the stage two task described in Section 2.6.5 using the paintbrush. Oviatt (2006) measured cognitive load with students speed, attentional focus, meta-cognitive control, correctness of problem solutions and memory to validate their results.

The Oviatt (2006) study provides possible insight into the lack of improvement in the Static Map section by the Interactive table → Static Map participants. Review of the qualitative comments from the audio of the session logs show that the participants felt they had to work harder to do the same task, thereby increasing their cognitive load:

- 'Bit hard to do without the house' Launceston General Public Participant # 23
- 'You got so used to the other one. When it is static you cannot play with it' Launceston general public participant #34
- 'Felt like I lost a limb after having done interaction' Launceston general public participant #2
- 'It would be nice if the static examples were interactive as well.' Launceston general public participant #18

These comments suggest the participants found the exercise mentally easier with the physical objects because the interface performs some of the manual work for them in addition to making it easier to visualise the situation.

Examination of the quantifiable statistics shows a statistical significant relationship exists between the frequency of use of tangible interface objects and post-test learning gain ($p<0.05$). Furthermore, a marginally significant relationship exists for the interim test ($p=0.05255$) when using tangible objects.

To explore the marginal significance a multiple regression model was created to evaluate the two separate components of the total frequency of tangible interface objects used (for Worked Examples and Practical Exercises). Subsequent linear modelling analysis proves the frequency of use of tangible interface objects in the Worked Examples have a significant relationship with the interim test score ($F(1,30)=5.97$, $R^2=0.1666$, $R_{Adjusted}=0.1382, p<0.05$). Interestingly, this would be the point where most participants would be exposed to the constructivist tangible tools for the first time.

7.4.3.2 Object influence on Results

The three dimensional form of the placement of the tangible object may have aided with visualising the mental model. In this context placement means the orientation of the base of the tangible object or the position of the tangible object on the table.

Observations of the general public participants showed that many placed the house model object upon the image of the house as seen in Figure 53 in Section 6.8. The house object activates the defendable zones when placed anywhere upon the table surface. The house does not need to be placed near or on the actual location of the house in the air photo image as demonstrated in Figure 38. Yet many participants deliberately placed the house object directly over the house in the image. Sometimes participants moved the house object on to this position, from where it was originally placed, whilst explaining a solution.

Some participants saw value in the tangible interface objects beyond their use as tools:

- 'Love having object it adds to mental picture' Launceston general public participant #19.
- 'I really thought the role of the objects seemed superfluous, while I was using them I found I was reflecting back to the video' Launceston general public participant #14

During the Static Map phase some participants made alternate uses of the interface tangible objects than their intended purpose:

1. Some participants used the objects as pointers whilst answering questions,

2. Some participants used the objects on the Static Maps anyway. E.g.. House placed in situ, or rake swept across the surface indicating changes,
3. The rake and chainsaw were sometimes used to draw bushfire features not envisaged by the design of the interfaces. E.g. fire breaks.
4. The objects were used to draw placement of fire breaks and/or dams. Fire breaks are not strictly part of the interface, This participant found it easier to picture their circumstances - 'Put a fire break here', 'Good did not have to remember where fire breaks were' and 'You need a dam near the fence' <indicates by using the tool on the map> and
5. One participant tapped the rake, rather than sweep, to indicate they would clean the bark and leaf litter from the ground.

The qualitative results show that the interface objects play many useable roles to support understanding, many beyond their original intended purpose.

Meanwhile, the quantitative results from Section 6.11 of the model of factors contributing to test scores and learning gain show:

1. *Frequency of use of interface tangible objects*
   explains 28.9% of the variance of the interim learning gain
   (Beta=0.605, $t(29)=2.37, p<0.01$), and
   explains 12.35% of the variance of the interim test score
   (Beta=0.357, $t(29)=2.86, p<0.01$), and

Together these results mean that participants who frequently used the house, rake and chainsaw to answer the tasks performed better than those who used them less frequently.

7.4.3.3 Comparison between Tests and Time spent on the Constructivist Tasks

The combined overall time spent on constructivist tasks was chosen as the preferred representation of the contribution of time to test scores and learning gains. The combined time is the sum of the time spent on the interactive *Worked Examples* plus the time spent on the interactive *Practical Exercises*.

The combined overall time was chosen because it would, by its nature, include cumulative effects. The *time spent on constructivist tasks* has a statistically significant relationship with the interim test score and the learning gain from the pre-test to the interim test as shown in Section 6.8.4 Relationship between Tests and Time spent on the Constructivist Tasks. This indicates that the time spent on the tasks contributes to improving the learning gain.

Speelpenning et al. (2011) showed that analysis of observational data indicated players more often announced that they were going to use one of the tools in the TUI condition compared to the multi-touch condition. Very few participants in the Launceston general public session behaved in this manner, those that did just seemed to do so to be polite.

The results from the model of factors contributing to test scores and learning gain (Section 6.1.1) show:

2. *Time spent on constructivist learning tasks*
   explains 42.36% of the variance of the interim test score
   (Beta=0.654,t(29)=5.23,p<0.001).

The result shows *Time spent on constructivist learning tasks* explains 42.36% of the variance of the interim test score which means the time spent completing the exercises with the model interface objects had a significant influence upon the interim test score (note: this improvement in interim test score is only for those participants who used the interactive interface first.).

It also means the more time participants spent *actively* answering the map-based constructivist tasks the better their interim test score (a component of this time was spent using the tangible interface objects).

7.4.4 Learning through Collaboration

All 19 participants, in 9 groups, improved their understanding of *Preparing for Bushfire* during the general public exercise, both using the traditional method and using the tangible Interactive Table *Preparing for Bushfire* Interface.

Unexpectedly, the groups did not outperform the individuals as anticipated from similar empirical studies (Speelpenning et al. 2011; Xie et al. 2008) and general collaborative group theory (Benyon 2010). It is not alone however, as indicated in the discussion in Schneider et al. (2010) who state that 'mediation analysis suggests that neither collaboration, exploration, nor playfullness were responsible for the improvement' of the learning gains within their TUI comparative study (Section 6.10).

Coding of audio recordings reveals frequent, almost continuous discussion between group members prior to actions using interface elements and before delivering answers to practical exercises. Knowles, (2011, p. 181) states 'Engaging adults as collaborative partners for learning satisfies their need to know' indicating the observed style of discussion/interplay is similar to such that contribute to learning.

Although Groups spent more time on task, than individuals, it seems that this collaborative effort did not contribute to additional learning gains, or higher test scores, over individuals' efforts (Section 6.10, p=0.8883 and p=0.8656.). This result is in contrast to that of Horn et al. (2011) who observed groups spent significantly more time on task than individuals regardless of the interface conduction. Horn et al. (2011) concluded that perhaps the type of interface might be less important than actively involving multiple participants. For the *Preparing for Bushfire* study involving multiple participants was not more important than the type of interface (Section 6.10).

The obvious likely reason is a flaw in the design of the interface, or an inflexible design of the experiment compromising cooperative operation. One reason may be caused by a lack of availability of interface objects as discussed in Section 7.9.1.3 Non-sharing of Tangible Interface Tools. However, collaboration benefits are possible as evidenced by the fact that the participants may simultaneously use the rake, chainsaw and house objects. Nevertheless, review of the session logfiles and audio transcripts shows every group used the interface tools sequentially, rather than simultaneously.

From this we can conclude that the group performance is only as good as individual use directly because group members used the interface in the same manner as individuals. Group participants did not concurrently use interface objects - a similar problem encountered by Stanton and Neale (Cited in Foster 2008, p. 133).

Collaboration was successful for the general public exercise in that all participants demonstrated a learning gain however the gain was no better than individuals.

7.4.5 Contribution of Engagement

The participants considered the tangible Interactive Table *Preparing for Bushfire* Interface highly engaging. The post exercise questionnaire asks carefully worded questions to quantify the engagement from all aspects of the system. It does this in two parts: the group of questions reported in Section 6.14 and the flow index – an intense engagement measure.

The questions delineate engagement within (Results Section 6.14):

1. Recent Aerial photography of the local region,
2. Interactive Mapping and of
3. Physical objects.

The median Likert response of 5 (Very High) for both aerial photography and Interactive Mapping is the highest possible engagement. Such very high engagement combined with positive responses identifying local data as an essential element of the interface (Section 6.15), clearly recognises the important influence of the Domain Specific Context of the interface information.

The Interactive Mapping contributes to the Domain Specific Context because it enhances the recent aerial photography of the local region for the interactive tasks. The Interactive Mapping, meaning the pan and zoom functions, vastly enhance the functionality of the mapping information by allowing zoom in to see more detail, or zoom out for a regional overview. These functions become integrally infused with the display of mapping information.

The tangible constructivist tasks (Worked Examples and Practical Examples) were carefully designed to appeal to traits of adult learners (Section 4.8.3). The design utilised multiple traits known to appeal to adult learners. The interface information is presented as a real life scenario using real world information from the local region. The exercise tasks are real actions, clearing leaves and bark, removing trees and ember-proofing. Such a structure was deliberately defined to meet the adult learning trait described by Knowles et al. (2005, p.40):

> Adults' orientation to learning is life-centered; therefore, the appropriate units for organizing adult learning are life situations, not subjects.'…' Furthermore, they learn new knowledge, understandings, skills, values

and attitudes most effectively when they are presented in the context of application to real-life situations.

It is more likely the combination of the relevance of the information along with the manner in which it is presented is the appealing aspect causing the engagement. This perhaps explains the high levels of engagement with the tangible Interactive Table *Preparing for Bushfire* Interface.

Engagement with physical objects is important as claimed by Etemad (1994) that students who are actively involved in learning by engagement with physical materials have a better grasp of information than those who learn through only visual or auditory methods. Our participants who experienced learning gains claim that using the physical interface objects was highly engaging (Section 6.14 Results). High engagement with TUI is not unique given that many TUI empirical studies also have found high levels of engagement (Antle, Tanenbaum, et al. 2011; Price, J. Sheridan, et al. 2010; Xie et al. 2008).

The immersiveness of engagement is so important that many empirical TUI studies use a measure of Flow to quantify the intense immersion of subjects (Section 6.14 Engagement and Flow). The original definition of Flow by Csikszentmihalyi is 'a state in which people are so involved in an activity that nothing else seems to matter'. The flow index measures the degree of concentration directly upon the objects and the interface. The presence of flow was clearly evident when observing participants. The flow index for the *Preparing for Bushfire* exercise equates to a value of *Agree* that flow from the results of Section 6.14 (mean=22.86, sd=3.87, Range=12-28, Cronbach Alpha of 0.81). Qualitative measures of Flow may be achieved in future studies if the sessions are recorded to capture the associated body language, demeanor and intense focus of the participants.

The flow index did not include any questions about the Static Maps session. Some positive engagement was shown for the Static Maps when it was used as the first session, however observation and review of audio logs shows much disappointment when the Static Maps were used after the tangible Interactive Table *Preparing for Bushfire* Interface session. The comments mostly expressed disappointment at the loss of functionality:

- 'Aw house does not work' Launceston general public participant # 17

- ‘Bit hard to do without the house’ Launceston general public participant # 23
- <while using the Static Maps> ‘You got so used to the other one. When it is static you cannot play with it’ Launceston general public participant # 39
- ‘I cannot use this’ <holding chainsaw in static exercises> Launceston general public participant # 57
- ‘Felt like I lost a limb after having done interaction’ Launceston general public participant # 2

These responses, combined with the lack of learning gain when the Static Maps were used last, indicate a lower level of engagement with the Static Maps than the Interactive Table. The qualitative statements indicate this is because of the reduced functionality of the mapping (no zoom in, zoom out or pan) and the elimination of the object functionality.

Price & Falco (2011) note that ‘Overall, fun and engagement have been measured through two main approaches: directly asking children about their experience, or quantifying physical clues during the interaction’. They, along with (Xie et al. 2008) note that ‘Read et al. propose engagement could be measured by observing the occurrence of a set of behaviour including: smiles, laughing, concentration signs, excitable bouncing, positive vocalization’. Given that smiles, laughing, concentration signs, excitable bouncing, positive vocalization are considered engagement for children, perhaps they should be considered as such for adults. These verbal responses actively demonstrate how absorbed participants are in the interface exercise task. In the public exercise at the library and museum it was noted participants were laughing, humming (a sound of contentment) or making sound effects when using the interface tangible objects. Review of the audio logs show: of the 64 participants, 7 laughed, 7 made sound effects and 3 hummed while using the tangible interface objects – 6 of these 17 were in groups. These positive vocalisations are possible indicators of engagement.

7.4.6 Predisposition to Bushfire

The participant’s 3% uptake of bushfire survival plans is consistent with the general trend of very low uptake of written Bushfire Survival Plans within Tasmania, however it is lower than the national average of 9% (Boylan et al. 2013, p.21;Mackie et al. 2013,p.8).

> Most residents in the South-East Tasmania area reported that they did not have a bushfire plan prior to the fire that started on 3rd January 2013. Residents commonly stated that they developed an unwritten bushfire plan as the fire approached their area and became a threat to them. These bushfire plans were often minimalistic, including their intended actions for the day (e.g. stay and defend, leave early, or wait and see) (Boylan et al. 2013, p.33).

This contributes to the claim that our participants are representative of our target audience.

7.4.7 Perception of the Occurrence of Learning

It was important to establish if adults felt they had learnt from using the tangible Interactive Table *Preparing for Bushfire* Interface experience, for two reasons:

1. their belief the system works builds faith and positive reputation for the system and
2. it builds confidence in their own abilities, potentially motivating them to act to prepare their home for bushfire.

The self-assessed perception of learning was used to assess a map-based multi-touch table study by Tanenbaum, et al. (2011) to assess the level of learning gain when using the Futura system. Futura is a collaborative environmental simulation game that can only be solved successfully when the collaborating partners understand the supporting sustainability theory. Therefore completing the Futura game itself establishes evidence of learning. The participant's perception of their own learning was used to quantify degree of learning for each participant.

7.4.8 Perception of Pre-existing Knowledge of *Preparing for Bushfire*

It is useful to know how many participants have a high perception of their bushfire knowledge because the perception may mirror their actual knowledge (Section 6.5). Participants with pre-existing high knowledge are expected to learn little from the *Preparing for Bushfire* session, hence their scores may negatively skew learning gains. Identifying such participants allows them to be removed from analysis, if required.

Experience from the General Public pilot trial at Kingston (Section 4.8.1) showed that participants with a high perception of their existing knowledge prior to the exercise:

1. Often made errors in the pre-test scores, sometimes scoring no better than their partner who indicated they possessed a low level understanding of *Preparing for Bushfire*.
2. Males were more likely to indicate a high level pre-existing knowledge.
3. 8 male participants of 20 declined to complete the post-test because of their belief their pre-existing knowledge was sufficient that they did not learn any new facts, however review of the audio from the session clearly contains comments where these same participants repeat facts that they themselves got wrong in the pre-test. These 8 likely felt they knew the bushfire facts at some time in the past, but have forgotten the correct facts over time without becoming aware of their knowledge lapse. The non-completion of the post-test impeded the evaluation of learning gain from the Interactive Table system.

Almost all participants in the Kingston deployment were pairs, often couples who lived together, while the participants from the Launceston deployment were mostly individuals. Perhaps the males in the couples were showing bravado in front of their female companions, whereas they may have behaved differently had they attended the table session individually.

The lack of correlation between the perception of prior knowledge and the test scores may be explained by the fact that the main rules for *Preparing for Bushfire* are common sense hence should be easily understood by any reasonable person.

The rules and guidelines require no specialist knowledge, merely founded on basic principles of fire. The Interactive Table allows exploration of complex fire scenarios, however the focus of the *Preparing for Bushfire* exercise is restricted to implementation of fundamental rules.

7.5 Participants

This study made sole use of adults who are members of the general public. Many empirical studies of tangible interfaces for adult subjects use post graduate students or undergraduate students (Schneider, Jermann & Zufferey 2010; Cuendet et al. 2012; Marshall et al. 2010; Schneider et al. 2013a; Tuddenham & Kirk 2010; Zuckerman & Gal-Oz 2013) such subjects represent only a small portion of the general public. They represent those who can afford to attend university, have skillsets suitable to complete university education and have a high level of academic ability. These requirements exclude many members of our society, so they do not truly substitute as members of the general public. Improving understanding of natural resource issues benefits all adults, of all ages and all disciplines, not just students. Consequently all the participants for this study were adult members of the general public.

This criterion impacts the design of the interface because the interface must clearly suit a wider varied audience than one deemed suitable for students. This research contributes to new knowledge by providing statistics about how general public adult members interact with tangible touch tables.

Adult member of the general public were chosen as the target audience (Section 3.5.3.3). All participants were asked 'Would you recommend this system to others?' because affirmative responses help to validate that general public adults are the ideal target audience. In response 100% of participants stated they would recommend the system to others. As further confirmation, as many as one third of all participants were referrals from previous participants via direct word of mouth. Many participants said they committed to undertake the experiment because they had been expressly informed by friends, neighbours or colleagues. This sentiment was expressed during the introduction or signs up stage, so was not recorded on the investigator session sheet, nor on the audio log.

7.6 Familiarity of Touch

Many adults in today's society are familiar with touch-based interfaces. It is almost ubiquitous with mobile phones, cameras and car navigation systems. The participants in the study considered themselves very familiar (Median=5 –Very Familiar, sd=1.06) with touch which seems in-keeping with the general population.

The touch table operates exclusively from touch, either from fingers or objects. However the system was optimally designed as a naturally intuitive system, so that experience with touch was irrelevant. This seems to be supported by Launceston General Public Participant 34 who claims 'Even if you are not familiar with touch technology it is possible to use the system for a learning experience.'

7.7 Answering the Research Question

This section outlines the answer to the research question:

> *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

The following mechanisms were found successful for *Preparing for Bushfire* for adult members of the general public:

1. Choose the application topic that appeals to the audience because of a combination of multiple factors tailored to adult learning: It is topical, it is important to them, audience realise they need to know about it anyway if they do not already, it is presented in a novel style, individuals are not alone in being new to the system, it is quick, it is interesting, it is not overwhelming, it is easy to use and it is simple to learn to use.
2. The constructivist learning techniques must be realistic, practical and pertinent. Using real world local spatial data such as air photos, property boundaries, with fire history provides the basis for these three criteria. The task exercises must be actual likely scenarios, they must be believable which will make them realistic and practical. Applying the task using local spatial mapping information makes it more pertinent for the participants, and therefore more important to them personally. Antle et al. (2011, p. 18) note 'the ability to link learning to real world contexts and objects, which is fundamental to Constructivist pedagogy'. Although their comment refers to children's learning the concept is still a valid constructivist perspective.
3. The tasks must be relatively quick to complete, if presented at a public venue. The general public have limited time and jobs or chores to do. They are likely to have little available time. The tasks must be presented in a manner that is more appealing than other available options for them to spend their time. Therefore focus on presenting the only a few of the most important concepts.
4. The air photos need to be of the surrounding region for the general public, although not necessarily their own property. This is perceived as reasonable because many members of the general public do not live as rural residents. Although, they are potential rural residents and they may one day choose to live in rural areas.

5. The interface should not require the ability to read. At the last census 20% of Australians, aged 15 and over, reportedly have the lowest level of literacy, while 50% fall in the lowest two categories (Australian Bureau of Statistics 2008).
6. Tangible interface objects add an extra dimension to the table interface. However the interface should only use objects as necessary.
7. Recommended object design rules for successful implementation in a tangible multi-touch table interface using map-based constructivist learning techniques:
    a. The technology must not be perceived by the end user as gratuitous. It must be fit for purpose. The application design must incorporate techniques/mechanisms for using the emergent technology so that the take away message is the goal of the application rather than the novel emergent technology (Mancini et al. 2010).
    b. Object choice must be appropriate and make use of the beneficial features of haptics/kinesthetics where possible (Kim & Dey 2010). For example to design multi-sensory features by incorporating texture or iconic colour.
    c. To reduce cognitive load, objects should be models of everyday objects rather than abstract or unfamiliar designs (Costanza et al. 2010).
    d. Aesthetics matter. High fidelity aesthetically appealing objects are preferred, unless they are so appealing users focus upon these to the exclusion of the interface.
    e. The objects need to have an inherent linkage/coupling to the interface (Price 2008b) or to the user of the interface. For example using a model of the Eiffel Tower to show the map of Paris appeals to those who have visited Paris. It brings forth memories – hopefully fond thoughts – thereby enhancing the appeal of the Eiffel Tower object.
    f. Objects must be functional. They must be graspable (able to be moved/picked up with forefingers and thumb), usable by either hand (Fitzmaurice 1996). They must have a base large enough for a Microsoft tag id (Microsoft 2011).
    g. Preferred construction method. Presently the general public of all ages seems to have a fascination with 3d printed objects. At the moment 3d printed models are well accepted. When 3d objects are used they do not need to be coloured, as observation shows that colour makes little difference to their acceptance. However tests by the author showed the

standard white plastic behaves as a reflector of infra-red, thus causing false touches.

h. The manner how objects are utilised in the interface must be purposeful and relevant for their purpose. For example: Allow an object to be placed upon the surface in any orientation, unless there is a specific reason that orientation matters (Microsoft 2011).
i. Be flexible with the table detection and response to the objects, allow room for error, because general public adults are generally unfamiliar with tangible model objects. They may use interface objects in unexpected ways.
j. Although not part of this study. 3d printed tangible interface objects are cheap enough that they may be gifted as a memoir of the experience, thus becoming a permanent memory prompt for later reflection.

The general public make better use of established stratified realistic constructivist task based scenarios.

7.8 Limitations to the Study

7.8.1 Internal Confounders

7.8.1.1 The Instructor

In the Kingston deployment (Section 4.8.1) the instructor was an active part of the experience, often correcting misunderstandings and misassumptions of the participants. Such a high degree of involvement is aimed to optimise the learning to obtain the highest possible improvement. However the downside by the integral incorporation of the instructor means the instructor's experience and knowledge, combined with their ability to disseminate explanations directly impacts the amount learned e.g. poor instructor means their participants are likely to learn less than participants with a knowledgeable instructor with good dissemination skills. Furthermore, the impact of the instructor on the amount learned adds an additional variable to the experiment, thus making it more difficult to accurate gauge the effect of the tangible interactive interface on learning.

For this reason a mitigating strategy was employed where the instructor was passive in the final general public deployment. This means that misinterpretations and misunderstandings were not corrected from one system to another. Lower scores in one system (static or interactive) should translate to lower scores in the second phase, simply because misunderstandings were not corrected. However, the instructor led use of the system should be reintroduced in a full deployment system, because it provides a mechanism to correct common misunderstandings.

7.8.1.2 Non-sharing of Tangible Interface Tools

In the interface there was only one of each physical interface object, although there were three objects in total. Therefore each of the interface object tools may only be used by one participant at a time, which Speelpenning et al. (2011, p.616) identify as a potentially detrimental attribute of TUI tools for their multi-touch table application for adult subjects. They explain:

> The physicality of the tool enables the action of picking it up and holding it, which may in turn cause a feeling of ownership. Psychological ownership is defined as the state in which individuals feel an object is theirs [37]. Thaler [36] uses the term 'endowment effect' to describe the idea that goods that belong to one's endowment are valued higher than identical goods that do not. Endowment contributes to a feeling of ownership. ……When a player picks up and holds one of the TUI magnifying tools, they and other players, may all sense that the object temporarily belongs to that player. Other players may then hesitate to take action on the object which was placed by and temporarily owned by, another player.

This ownership inhibits other group members from using the TUI tools, hence detrimentally impacts the performance of the group. No such behaviour was observed in the *Preparing for Bushfire* study. Other group members were commonly observed to use tools as they were relinquished often simply to adjust or value add to the answer.

7.8.1.3 Interface Objects behave as Prompts

The participants were told a brief description of the interface objects at the start of the Interactive Table session. The rake is described verbally at the commencement of the exercise by the words: 'The rake is used to clear away on-ground fuel such as leaf litter and bark'. This description may act as a reminder to clear leaf litter and bark. Furthermore the interface objects themselves are effectively continuous reminders of bushfire preparedness actions (Figure 64).

Figure 64: Tangible objects of the *Preparing for Bushfire* Interface - Rake, House and Chainsaw.

A similar problem is noted by (Schneider et al. 2013) for their neuroscience TUI vs text book experiment. Their instructional prompts are only provided for the TUI session, not for the text book session, hence is a potential confounding influence.

7.8.1.4 Guessing Answers on the Pre-test

Participants were discouraged from guessing answers. Some participants openly stated that they knew nothing about bushfire or *Preparing for Bushfire* so did not know some of the answers, yet because some questions were multi-choice they recognised that they had a chance to correctly guess the answers. Review of audio session logs provides insight into the reasons why participants guessed. Several participants indicated that they felt dumb and furthermore had nothing to lose by guessing. 'I feel so stupid. I cannot believe I do not know this', 'I guessed the last couple', 'I do not know the answer to this question. I'm going to guess because I have nothing to lose and I do not want to look like I do not know anything.'. They indicated they would rather guess than not record an answer as it would make them appear smarter if they correctly guessed the answer. Some participants guessed very well. No benefit for the research is achieved by those who successfully guessed answers in the test as successful guessing perverts the results to lessen the actual true learning gains.

Future exercises should include a tick box next to questions on the pre-test to indicate questions that were guessed. This would be easy to implement since participants were eager to mention when they guessed. These tick boxes should be on the investigators session note sheet rather than the participant pre-test questionnaire.

7.8.2 External Confounders

7.8.2.1 Active ongoing Promotion of Bushfire Education

Bushfire is a serious concern in Australia. Fire agencies continually actively promote bushfire education (Hughes & Steffen 2013). Emotive radio adverts and TV advertisements are frequently played during bushfire season and as bushfire season approaches. These are specifically designed to inspire action and impart important key facts.

If the tangible Preparing for Bushfire interface on the Interactive Table prompted memories of the tv adverts or previous bushfire education, then this is not a confounder because it is part of the nature of adult learning (Section 2.3.3).

7.8.2.2 Object Design limitations

The tangible object design process is complex, demanding in time to design and create purposeful custom objects. It is very difficult to get right (Section 2.5.1). Yet important, because as reinforced from *Around the World* (Appendix 1), correct representation means greater use, enjoyment and engagement. Successful design using strong metaphors creates a high degree of coherence between physical and digital objects (Section 2.6.5) – a significant component of the *Preparing for Bushfire* system Koleva et al. (2003).

Participant feedback indicates strong metaphors are present in the tangible interface objects of the house, rake and chainsaw:

- ‘I love the house - place it and instantly see the zones’ Launceston general public participant # 2
- ‘Love having object it adds to mental picture’ Launceston general public participant # 19
- ‘Chainsaw and rake was beneficial to show what I was talking about’ Launceston general public participant # 16

7.8.3 Contribution from Interactivity

The benefits seen might be because of the use of interactivity and not specifically due to the tangible user interface elements. This could have been tested by adding a third condition to the user study which provided interactivity without the tangible interface, and so provide an alternate method of measuring the learning benefit of interactivity and then the benefit of the tangible interface.

7.8.4 Retention of Understanding and Motivation

A retention study was not conducted, although initially intended. The questionnaire gathered contact information to conduct the retention study to measure motivation and deep understanding over time, however this work was not undertaken.

7.8.5 Technical Design Issue of Touch on Microsoft PixelSense

Unlike tablets and smart phones, the PixelSense SUR40 uses infra-red for touch detection. Capacitive touch is too expensive for table sized touch, while infra-red is much more cost effective. Unfortunately, infra-red touch detects false touches from everyday infrared sources including fluorescent lighting, sunlight and accumulation from reflectance of light. This includes light reflected off white or silver objects such as bracelets and watch bands, or any silver or white surface of an object used as part of an application interface. Most regrettably this includes the default plastic utilised for 3d printed objects - the optimum method to create tangible tagged table objects.

These however, are not the only source of false touches for touch tables. False touches are commonly caused by trailing fingers (usually the little finger), shirts sleeves, objects placed upon the bezel that slightly overhang on to the screen and id cards worn around the neck.

The *Preparing for Bushfire* application recorded all touches, including object touches, to a logfile for each session. Analysis of these logfiles shows the surprising extent of false touches detected by the table. All true touches were recorded on a instructor observation sheet by the investigator. Every placement and movement of interface objects was recorded by observation by the investigator, as was all map navigation (pan and zoom). The start and end time of each section of the user session was recorded. Therefore it was straightforward to match the finger and object touches to the touch logfile. The logfile was intended as the source to provide the duration of the touch or duration of use of interface object.

Frequent dropout of touch tracking of objects is an issue, however the logfiles reveal the full extent of the problem. Ideally the touch logfile should show a touchdown for every finger/object, then a touchmove when the finger/object moves, finally a touchup when the finger/object is removed. However the table frequently loses track of the finger/object so the logfile sequence for a finger touch-move-touch off is commonly: touchdown, touchmove, touchdown (again with new finger id), touchmove, touchmove, touchdown, touchmove, touchup. The single finger touch is recorded as three styles of finger touches. Similar results occur for objects which makes it difficult to track the same object as the system believes each object touchdown is a new second object.

Observation of hundreds of first time PixelSense adult users shows that participants attempt to use the Interactive Table in the manner with which they are use tablets and smart phones. Their touch movements and touch gestures are too fast and too close together to be optimally detected using infrared. Furthermore they do not use bimanual gestures. This same lack of bimanual use is noted as a problem prior to widespread use of smartphones and tablets by Terrenghi et al. (2007).

False touches are reduced by optimising the environment around the PixelSense, stringent interface object design and user education prior to first use. False touches are reduced and managed by slow steady stable touch actions. PixelSense applications lose none of their effectiveness with these mitigation strategies in place, as evidence by the written participant response:

> 'The sensitivity of the touch screen is not perfect but does not get in the way of the interaction.' Launceston general public participant

7.9 Future Work

7.9.1 Extend the Comparative Study to include a Multi-touch only Interface

It would be a worthwhile exercise to conduct a future study with three interface conditions; Static, Interactive Multi-touch interface, and Interactive Multi-touch interface with Tangible UI. This will provide a standard accepted method to separate out the influence of an interactive multi-touch interface versus a tangible interactive interface. Furthermore, it provides an avenue to compare the multiple regression contributing factors model to the comparative differences here, specifically for the tangible component.

Development of a multi-touch interface would contribute to development of less expensive systems.

7.9.2 TFS Implementation of a Cheaper Budget System

Although limited by budget constraints TFS attempted to implement the key features of the system. The initial proposal is to apply a cut down version of the technique to largest available touch only pc (27in display). The version will be a cut down version because of available funding. This follows previous plans to trial the system on a 12 DELL Windows 8.1 tablet.

TFS determined that the Tangible Table *Preparing for Bushfire* system to be a worthwhile endeavour from observations by Peter Middleton Team Leader Community Development Coordinator and in-person feedback from Fire Brigade volunteers and Bushfire Ready Neighbourhoods group members:

> 'You may not be able to use the table but this is the closest thing to the table
> – it has the most functionality' Peter Middleton

Alternative solutions include consideration for a Google Earth version of the GIS style interface for community groups to self-administer. Although, Google Earth lacks the hands-on aspects and the collaborative benefits associated with a horizontal orientation, it does contain the digital mapping of current air photography and fire history. So it is useful to continue to use after the initial use of the tangible touch table system.

7.9.3 Recommendations for TFS - Clear around Shed

Observation of the community groups showed that when discussing clearing and ember proofing, their home, that residents forget to clear about their out-buildings some of which are close to the home. Residents clear around a defensive area around their house, but not necessarily around their shed. Why is this significant? It is very significant because male residents significantly value the contents of their sheds. Often the sheds contain valuable cars, equipment, hobby fundamentals and family memorabilia not stored in the house. TFS doctrine does not mention/ promote clearing around sheds. Sheds are just as important to the residents as the primary residence. This finding was consistent for all communities visited: Lilydale, Lorinna, Ferntree, Lachlan and Kingston.

7.10 Summary

This chapter demonstrates the confirmation of the hypothesis for the case of *Preparing for bushfire*:

> *A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources.*

It does so by the mechanism of following a set of guidelines for the choice of topic, constructivist task design, interface object design, and object to surface operational functionality.

The general public exercise has a meaningful number of participants (Guest et al. 2006). All participants are representative of the target audience.

The learning gain from tangible map-based constructivist learning tasks is significant ($p<0.001$). Furthermore, the learning gain is significantly greater than when using the traditionally available alternative ($p<0.001$). In fact, the difference is so large that the initial learning gain from the tangible system is equivalent to the overall learning gain from using the traditionally available alternative followed by the Interactive Table session (Static Map→Interactive Table)($p=0.116$ n.s).

Chapter 8: **Conclusion**

'No thief, however skillful, can rob one of knowledge and that is why knowledge is the best and safest treasure to acquire.'
— L. Frank Baum, The Lost Princess of Oz

8.1 Introduction

Following on from the discussion this chapter summarises outcomes from the thesis. It starts by revisiting the research purpose. The results of the hypothesis test is presented with a concise explanation. This is followed by evidence that the methods applied in the thesis were valid. Lastly, the limitations are presented, followed by recommended future work.

8.2 Research Purpose

The problem addressed within the research is the ongoing issue of raising the awareness of significant natural resource issues to the general public. The problem is one of providing an understanding to adults that is motivating and inspiring to encourage positive action to reduce their own or community risk.

The solution involves providing a pathway to encourage adults as the primary decision makers to develop an understanding of the complex nature of natural resources, so that they have an appreciation of the effects of their decisions upon the environment.

The hypothesis was derived during the literature review from a combination of factors linked to the research problem:

- the nature of natural resource information,
- learning theories,
- principles of adult learning, and
- empirical TUI studies.

The spatial nature of natural resource information lends itself to a map-based solution, while the review of adult learning preferences and learning models indicate constructivist tasks as likely to encourage learning (Knowles et al. 2005; Piaget 1962; Rick et al. 2009). The literature review indicates that an Interactive Map-based tangible touch table system using constructivist learning tasks has the potential to improve understanding of natural resources for adults.

The thesis hypothesis is:
A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources.

This hypothesis contains the following research questions:

1. *What is required for comprehension of dynamics of natural resources?*
2. *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

8.3 Response Addressing the Hypothesis

The results from chapter 6 combined with their discussion in chapter 7 show that 64 participants demonstrated improvement in their understanding of the subject ($p<0.001$, Section 6.6). The learning gain from tangible map-based constructivist learning tasks is significant ($p<0.001$). Furthermore, the learning gain is significantly greater than when using the traditionally available alternative ($p<0.001$, Section 6.7). In fact, the difference is so large that the initial learning gain is equivalent to the overall learning gain from the scaffolded learning when starting with the traditionally available alternative immediately followed by the Interactive Table session (Static Map→Interactive Table)($p=0.116$ n.s).

The participants indicated that as a direct consequence of using the tangible Interactive Table *Preparing for Bushfire* Interface:

- 94% believed they learnt something about preparing for a bushfire (94% definitely, 6% may be),
- 70% felt inspired or motivated to become more prepared for a bushfire (70% definitely, 28% may be) and

- 87% believed they had a deeper understanding from this experience (87% definitely, 13% may be) (38 participants answered this question).

These results are confirmation of the hypothesis for the case of *Preparing for bushfire*:

A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources.

This outcome will be broken down further by considering the results of each of the research questions.

8.3.1 Research Question One

The first research question was asked because the responses were required for the development of the interface. The question is:

What is required for comprehension of dynamics of natural resources?

This question was answered using a semi-structured interview of 19 natural resource experts. The experts were asked about priorities and composition of natural resources issues. The detailed results are available in Appendix A1.1. The results show key messages, lists common misconceptions, names of local experts, source of data, significant natural resource issues, and sample real world scenarios (Table 24). These cumulative responses were used to develop the main TUI.

Table 24: Urban Sprawl natural resource issue showing its cause and effect relationships.

Urban Sprawl

id	Issue	Significance	Real World Example	What should be known which is generally not well understaood?	Interconnectedness -cause & effect
13	Urban Sprawl	Much good farmland is going under houses	Ulverstone, Tasmania	Living the aussie dream of a suburban block costs us in potential agricultural production.	n/a
12	Alienation of productive land from agriculture	Loss of productive land to housing and development reduction, Elimination by modified land use policies and planning constraints on use adjacent agricultural land by urban neighbors.	Many towns and cities across Australia, Local towns such as Scottsdale Devonport, and Burnie.	The extent of land currently alienated from productive use and the amount of land that would potentially be lost.	Increasing urbanisation and poor planning policies resulting in some of better land taken out of productive use. It is also the cheapest land to build on.
9	Impact of Urban sprawl on future and food production systems	Highly desirable arable land is a limited resource, there are other options for the spread of urban and peri-urban communities than class 1-3 land	It now takes 20 minutes driving from Burnie to reach the first substantial farm. The rest of the land is unlikely to return for some level of food production. Small blocks removed from water resource.	Spatial distribution of class 1-3 and class 4 should not be used for expansion of towns as it reduces the available land that can be used for cropping and food production	Only a small finite amount of land is highly suited for cropping and if this land is built over by houses then it is no longer available for food production. This is bad in a world where the population is increasing and we need more food to be produced.
11	loss or fragmentation of habitat	The destruction to habitat and the increased risk of invasive species spread, leading to increased threat of localised species depletion.	South east Queensland has some massive urban and prei-urban growth over the last 20 years leading to the Koala and other spices being threatened.	Further urban expansion will fragment remnant threatened habitat	Loss of habitat gives preference to fires which leads to degradation
22	Competition for land area between human population growth and the environment	Biodiversity is essential to the well being of human communities present and future and with incipient climate change and population pressure this resource will be tested. Expansion of farming requires land clearance. Urban pressures are significant in the southern Tasmania with peri-urban expansion taking land away from farming bringing with it weeds and pests and diseases.	The midlands of Tasmania land being cleared for use in farming.	Adaptive management could improve the current methods of managing.	land clearance causes a loss of biodiversity in both land and waterways

Additional References to Urban Sprawl in other natural resource issues

7	Water quality and quantity		Drought, flood, urbanisation, industralisation		

8.3.2 Research Question Two

This question concerns identifying which factors contribute to encouraging understanding. The research question is:

> *What are the mechanisms by which a tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources?*

It does so by the mechanism of following a set of guidelines for the choice of topic, constructivist task design, interface object design, and object to surface operational functionality.-The full set of design criteria is available in Section 7.7.

The actual factors that contribute to encouraging understanding were identified by multiple regression analysis. Significantly contributing factors were combined into a model to quantify the contribution each made to improving understanding (signified by learning gain and an improved test score). Regression models that quantify the influence of contributing factors for both the interim test score and the learning gain from the pre-test to the interim test show (Section 6.11):

1. *Frequency of use of interface tangible objects*
   explains 28.9% of the variance of the interim learning gain
   (Beta=0.605, t(29)=2.37,p<0.01), and
   explains 12.35% of the variance of the interim test score
   (Beta=0.357,t(29)=2.86,p<0.01), and
2. *Time spent on constructivist learning tasks*
   explains 42.36% of the variance of the interim test score
   (Beta=0.654,t(29)=5.23,p<0.001).

The results show *Frequency of use of interface objects* (house, rake and chainsaw) and *Time spent on constructivist tasks* explain 54.7% of the variance of the interim test score. In addition, the *Frequency of use of interface objects* influences 28.9% of the learning gain, which means the time spent completing the exercises with the model interface objects had a significant influence upon both the interim test score and the learning gain.

Together these results mean that participants who frequently used the tangible objects to answer the tasks performed better than those who used them less frequently. It also means the more time participants spent *actively* answering the map-based constructivist tasks the better their interim test score (a component of this time was spent using the tangible interface objects).

8.4 Validity of the Method

The general public exercise had a meaningful number of participants (Guest et al. 2006). The number of participants equalled or exceeded the minimum number required for their analysis (Section 3.5.2). In addition, all participants are representative of the target audience.

8.4.1 Repeatability

The entire exercise can be repeated because the implementation procedure containing step by step instructions are available in chapter 5 Experiment Implementation. The detailed implementation procedure allows a full test of the hypothesis by evaluating constructivist map-based tasks against a current traditionally available system. The detailed steps allow the exercise to be repeated. A copy of the questionnaire, and the supervisor assessment sheet are in Appendix 9.

8.4.2 Premise

The research tested the underlying assumption that the general public does not have an adequate understanding of natural resources.

- 80% of natural resource experts believe that the general community has a poor understanding of the interconnectedness of natural resources, which agrees with the original premise, and
- Adults engaged with and enjoyed the touch table map metaphor with tangible objects successfully applying spatial reasoning with explorative tasks ($X2$ (3, $N = 19) = 56.62$, $p < .01$).

  The underlying premise to the solution relies upon adults using map-based tasks on a touch table. This test established that the concept appeals to adults.

8.4.3 Application Topic

The application topic *Preparing for* Bushfire was chosen with justifiable cause as detailed in Section 4.3**.** It is a complex real world issue which directly impacts people's lives.

8.4.4 Testing and Evaluation

The main interface was pilot tested for four days at the Kingston shopping complex. It was a full implementation test which included running the experiment on 20 residents in the Kingborough region. The lessons learnt from this experience helped to correct the interface design, automated data collection, location site choice and experimental design.

8.4.5 Founded on Established Methods

The initial stages similarly used well founded methods. The first stage used a semi-structured interview of open and closed questions for natural resource experts. The questionnaire made some use of Likert scales as they are specifically designed to collect perceptions and are the most common method to 'elicit opinions' (Benyon, 2010).

The within subjects cross over design is founded on similarly structured studies of (Schneider et al. 2013a; Tuddenham & Kirk 2010). The presence of learning was evaluated by paired t-test (Quinn & Keough, 2002) similar to the tangible experiment of Kraaijenbrink et al. (2009). Meanwhile, the learning gain was assessed similarly to TUI studies of (Antle, 2012; Marshall et al. 2010; Streng et al. 2009) by measuring the change in the scores from the pre-test through the interim test to the post test.

The preliminary *Preparing for Bushfire* application was pilot tested with the general public for a week at the Kingston shopping centre. The lessons learned from the experience fine-tuned the exercise method, measures, constructivist tasks and reporting mechanisms for the experiment design for the main deployment.

8.5 Contribution to Knowledge

The contribution to knowledge is the set of design rules for adult user preferences of topic choice, constructivist task design, interface object design, and object to surface operational functionality. These design rules were the guidelines behind the positive results for the tangible touch table *Preparing for bushfire* interface. The full set of design criteria is available in Section 7.7.

Adults felt inspired and motivated from using the tangible interface exercise which applied these guidelines in the *Preparing for bushfire* context. Inspiration and motivation are indicators of adult learning (Knowles et al. 2005).

Secondly, it is unusual that the 64 adults in this study were members of the general public rather than students who seem to be the traditional adult participants in university studies. The general public perspective is unique and contributes to the knowledge pool.

8.6 Limitations

A comprehensive list of limitations is available in the Interpretation and Discussion Chapter Section 7.8. Each of the core limitations have been reviewed. Some strategies were implemented to mitigate their effects, however the effect of active ongoing promotion of the bushfire education cannot be quantified.

The most contentious limitation is that Interface objects may act as prompts, as constant visual reminders because the objects are constantly present on the bezel around the table surface. Their presence may remind the participant of the actions they need to undertake during simulation exercises. A similar problem is noted by (Schneider et al. 2013) where they suggest using exactly the same wording for each group. This suggestion was implemented in the exercise. However, it does not seem to address the fact that the model house, rake, and chainsaw were visibly present at all times, so may have acted as a visual prompt rather than a verbal prompt. Perhaps removing the interface objects from sight unless in use, could suffice to mitigate the problem.

8.7 Future Work

The application of *Preparing for Bushfire* uses commercially available hardware and software APIs, with publically available spatial data and imagery, using object design guidelines from this thesis. The object functions and all the operational code for the interface was written as modules, so are easily reconfigured. The spatial data uses pointers to datasets, so is also easily customised.

The following three suggestions for future work are feasible:

1. The application framework could reasonably be reconfigured to be applied to an alternative natural resource issue, such as invasive weeds, using the design of the

Preparing for bushfire system as a guide. Additional work would include designing the constructivist tasks and building the tangible models, along with a consultative, iterative process with evaluation.

2. The *Preparing for bushfire* experience hinted that the application framework may suit limited emergency management training scenarios.
3. However, the most potentially suited extension is as a community *Preparing for Bushfire* tool. Each of the three bushfire community groups involved in this study requested a variation of the application specifically suited for their own bushfire community group. A suitable customised bushfire community group interface would be a straight forward project applying the similar principles as the general public application.

8.8 Conclusion

These results and discussion presented are confirmation of the hypothesis for the instance of *Preparing for bushfire*:

> *A tangible multi-touch table interface using map-based constructivist learning techniques encourages understanding of natural resources.*

Appendix 1 – Stages One and Two Results and Discussion

A1 Stage One Results and Discussion

A1.1 Results and Discussion

The aim of stage one is twofold:

- To define the boundaries of *understanding of natural resources* stated within the research question and to
- Validate the underlying premise and fundamental choices for the solution.

The qualitative study was completed using 19 natural resource experts from 18 unique agencies including NRM, conservation, forestry, government and industry (Figure 14). The experts addressed the major critical knowledge gaps, explanations of key relationships, real world scenarios, related projects and sources of spatial data. From the results, the issue of water quality and quantity is considered the most significant natural resource concern, because it has the broadest adverse impact on our environment.

The completion time of the survey was initially estimated to be between 20-30 minutes, however the average length of audio recordings of the interviews was 41 minutes, with a range between 20 minutes to 80 minutes. Overall, the participants themselves had an average of 21.5 years of experience in natural resource disciplines ranging from a minimum of 1 year to a maximum of 43 years. The single-year experience participant is an outlier that was removed because of her limited experience, its removal improves the average experience by 1.1 years to 22.6 years.

The 18 responses (outlier removed) is more than the minimum 15 required for the study (Section 3.5.1).

The quantitative data was analysed by Excel, while the qualitative responses were coded within NVIVO.

The premise that the general public doesn't have an adequate understanding of how changes in one natural resource affects another (interconnectedness) directly or indirectly, is assessed by first establishing if such an understanding is important, then secondly by quantifying the perception of experts' in the level of understanding of the general public.

The contribution of interconnectedness was assessed by quantifying the perception that a "Lack of understanding of the interconnectedness of natural resources adversely impacts the environment". In all, 86% Agree, Somewhat Agree, or Strongly Agree, whilst no expert disagrees (as illustrated in Figure 65). While this points to a fundamental agreement of the issue, the extended comments below show the question has layers of complexity:

- "*Impacts are not always negative. The problem is not so much the environment, but peoples understanding of their convictions*",
- "*People understand the interconnectedness but don't want to admit they have an impact on other people*", and
- "*Lack of appreciation of potential impacts is very important*".

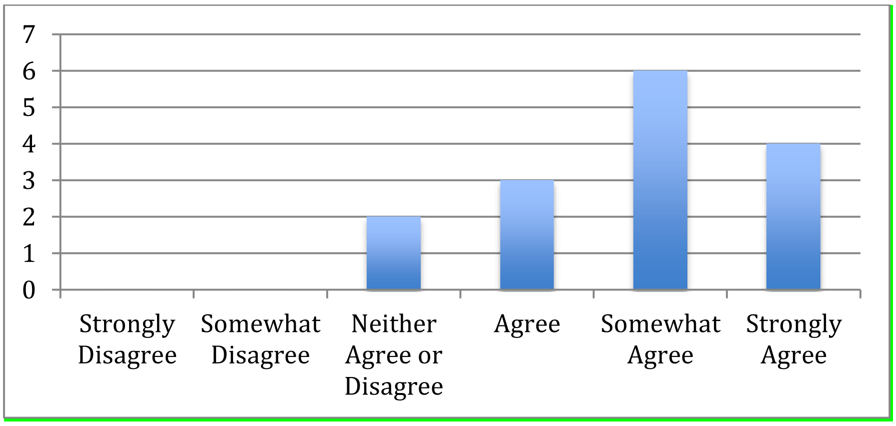


Figure 65: Lack of understanding of the interconnectedness of natural resources adversely impacts the environment.

The perception of the understanding of the general public is extracted from the question:

> Q3 To what degree do you believe that the general community understands the interconnectedness of natural resources?

The results, as seen in Figure 66, show that 80% believe that the general community has a poor understanding, 15% believe there is some understanding while only one respondent believed that the general community has a reasonable understanding of the interconnectedness of natural resources.

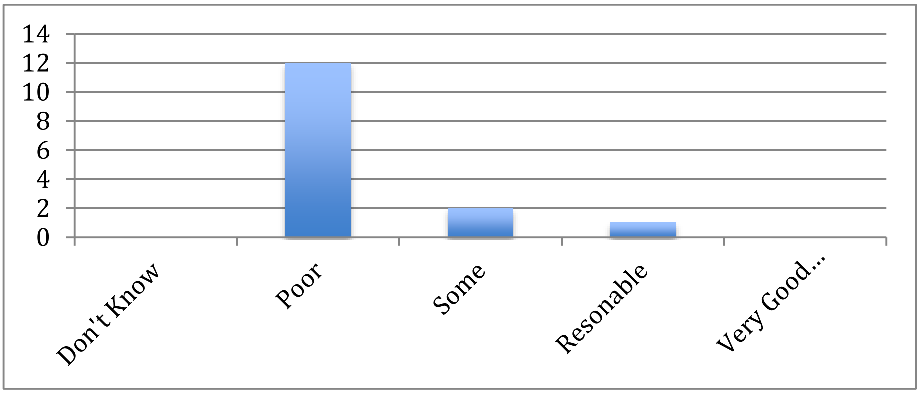


Figure 66: To what degree do you believe that the general community understands the interconnectedness of natural resources

A primary purpose of this survey was to identify real world significant natural resource issues. A total of 45 issues were identified which grouped intuitively into eight topics. Each new topic was created when an issue was identified by more than one expert. The topics are shown below in Table 25: Main natural resource issues

Table 25: Main natural resource issues

Issue	Count
Water Quality and Quantity	11
Exotic Flora and Fauna – Weeds and animal pests	9
Loss of Habitat	8
Abandonment of Private Forestry	6
Urban Sprawl	5
Soil Erosion	5
Mining in the Tarkine Wilderness	3
Climate Change	2
Lack of sharing of monitoring & evaluation flora/fauna/land data from single scope projects	2

Water quantity and quality was clearly the highest concern, closely followed by weeds, loss of habitat , and the issue of abandonment of private forestry. Almost all of the survey participants were from Tasmania, so it is not unexpected that the results show 20% of the issues had a Tasmanian bias. This 20% includes the issues of the decline of Tasmanian Devil, mining in the Tarkine wilderness, and the abandonment of private forestry. The abandonment of private forestry is a relatively new issue reflecting the collapse of the private forestry and plantation industry in Tasmania. The affected private forests are no longer effectively managed for weed, fire, and pest control, which cause concern for surrounding land managers.

Natural resource issues occur at a range of scales, from small pockets of isolated incidence to worldwide concerns. Some worldwide problems also occur at local, regional, and statewide scales. The participants were asked to indicate the on-ground extent of their impact (Figure 67: On-ground extent of the natural resource issues identified in the survey). Over 40% of the natural resource issues were identified as being global, 22% being statewide, 20% being regional. The remaining 17% were municipal and isolated.

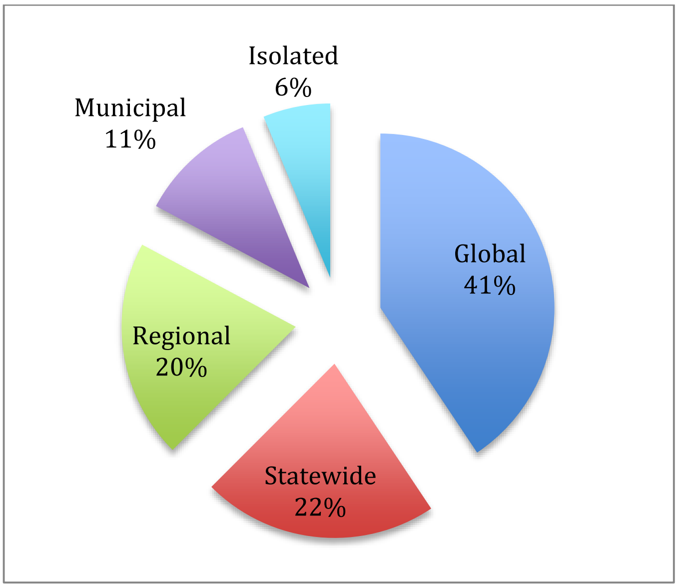


Figure 67: On-ground extent of the natural resource issues identified in the survey

Although all these natural resource issues are significant, for some of these issues educating the public does not necessarily have any impact on the problem. This question was asked for each natural resource issue, and in 11 of the 45 cases public education was regarded as not likely to have an impact. In these instances the coupled comments indicated that the public had no influence over the impact, and that any education needed to be focussed on a specific target audience, such as land managers and policy makers.

The educational value of the natural resource issues for the research lies in the being able to represent the issue as an educational task where the key points are understood, common misconceptions are removed, and where the interconnectedness is shown as cause and effect relationships. The information cultivated for the design of the educational tasks was extracted from the following four questions:

1. What makes this issue significant?
2. Describe a real world scenario where this issue occurs.
3. What should be known by the target audience that is generally not well understood?
4. How is the interconnectedness of natural resources involved in this issue?

This information is collated for each natural resource issue. The responses for Urban Sprawl are displayed in Table 26. The responses provide important explanations as to why Urban sprawl is a significant problem as evidenced by the very first response in the Significance column - “Much good farmland is going under houses”. The responses also provide explanations that will be incorporated into educational tasks to help to create an understanding about the issue of urban sprawl. The information in Table 26 is able to be represented as concepts and facts delivered using the interactive hands-on visual method of the proposed map-based visualisation TUI system. The delivery mechanism itself will enable the information be presented in manner that is easier to process and understand, than a table of facts and figures.

Table 26: Urban Sprawl natural resource issue with its cause and effect relationships

Urban Sprawl

id	Issue	Significance	Real World Example	What should be known which is generally not well understaood?	Interconnectedness -cause & effect
13	Urban Sprawl	Much good farmland is going under houses	Ulverstone, Tasmania	Living the aussie dream of a suburban block costs us in potential agricultural production.	n/a
12	Alienation of productive land from agriculture	Loss of productive land to housing and development reduction, Elimination by modified land use policies and planning constraints on use adjacent agricultural land by urban neighbors.	Many towns and cities across Australia, Local towns such as Scottsdale Devonport, and Burnie.	The extent of land currently alienated from productive use and the amount of land that would potentially be lost.	Increasing urbanisation and poor planning policies resulting in some of better land taken out of productive use. It is also the cheapest land to build on.
9	Impact of Urban sprawl on future and food production systems	Highly desirable arable land is a limited resource, there are other options for the spread of urban and peri-urban communities than class 1-3 land	It now takes 20 minutes driving from Burnie to reach the first substantial farm. The rest of the land is unlikely to return for some level of food production. Small blocks removed from water resource.	Spatial distribution of class 1-3 and class 4 should not be used for expansion of towns as it reduces the available land that can be used for cropping and food production	Only a small finite amount of land is highly suited for cropping and if this land is built over by houses then it is no longer available for food production. This is bad in a world where the population is increasing and we need more food to be produced.
11	loss or fragmentation of habitat	The destruction to habitat and the increased risk of invasive species spread, leading to increased threat of localised species depletion.	South east Queensland has some massive urban and prei-urban growth over the last 20 years leading to the Koala and other spices being threatened.	Further urban expansion will fragment remnant threatened habitat	Loss of habitat gives preference to fires which leads to degradation
22	Competition for land area between human population growth and the environment	Biodiversity is essential to the well being of human communities present and future and with incipient climate change and population pressure this resource will be tested. Expansion of farming requires land clearance. Urban pressures are significant in the southern Tasmania with peri-urban expansion taking land away from farming bringing with it weeds and pests and diseases.	The midlands of Tasmania land being cleared for use in farming.	Adaptive management could improve the current methods of managing.	land clearance causes a loss of biodiversity in both land and waterways

Additional References to Urban Sprawl in other natural resource issues

7	Water quality and quantity		Drought, flood, urbanisation, industralisation		

The experts were consulted about their dissemination methods and preferences by asking the open question: *"If you could use any tools or techniques to improve the understanding of natural resources, what would you choose?"* The highest five responses were:

- Education,
- Interactive,
- media,
- tools, and
- Visual information.

This response compares well to the proposed TUI system which is educational, interactive, uses physical tools to show visual information.

Lastly the experts were asked about suitable target audiences by the open question: "Is there a particular group that would benefit from a greater understanding of the interconnectedness of natural resources?" The answers with more than two responses were:

- General Public (4),
- Politicians (3),
- Teachers (2), and
- Policy makers (2)

The responses provide support to the research target audience of the general public as the considered the group that will most benefit.

A2 Stage Two - Results and Discussion

A2.3 Tangible Object Creation

Sourcing tangible objects is very time consuming. So, what is the easiest way to create tangible model objects for tabletop interfaces?

The tangible object can be sourced ready-made, or constructed as part of the development of the interface. It is unlikely that the tangible objects needed for the interface are available for purchase in shops. If a close match cannot be found from anything available, then the object must be built. Of the tangible objects in the *Around the World* exercise (Figure 68) 3 objects were sourced: UTas from UTAS media office, Paris from a keychain and Elephant Park from a fridge magnet. The remaining 3 were built: Las Vegas, Sydney and Giza (Figure 68). The Sydney and Giza models were built using modelling clay, while the Las Vegas model was built from a dice and two small playing cards glued together.

Figure 68: Tangible model objects from the *Around the World* exercise.

However a quick effective method is to use 3d printing, provided that the construction material is not important. The experience of observing hundreds of tangible touch table users during this thesis research showed 3d printed objects to be highly appealing to adults. It was constantly observed that the general public appear to have a fascination with 3d printed objects. They would pick up 3d printed objects and inspect them whilst discussing the creation process, often walking off with objects still in their hand. Adults seemed eager to engage with the 3d printed objects. Printing 3d models is straightforward because of the proliferation of 3d printers and the ready access to people with a 3d modelling skillset. The online libraries of 3d models contain many models with errors that invalidate the 3d printing process. These libraries are not to be trusted from the experience of this researcher.

A wide range of objects of assorted construction methods were trialled in a workshop at the Spatial Sciences Conference workshop. Numerous conference attendees attempted to walk off with one of the tangible objects. In every such case the object was a 3d printed object. Public demonstration of the research also raised the issue of fascination with 3d printed objects which were often taken by people using the system. It required vigilance to avoid losing too many interface objects.

Perhaps the only downside is that the default 3d printed colour is white. White causes false touches from reflected light which in-turn is detected by the touch recognition system of the PixelSense touch table. One solution is to spray paint the printed model to a non-reflective colour as shown in Figure 69. Spray painting applies a thin consistent coat of paint, so is preferred to hand painting which lacks such consistency.

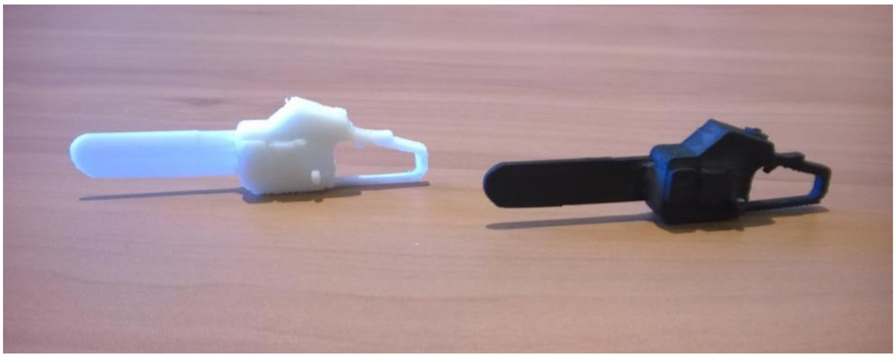


Figure 69: 3d printed tangible objects. The original white model reflects light causing false touches, whilst the spray painted black model is detected only once.

Appendix 2 - Lilydale Bushfire Preparedness Education Meeting Summary and Results

Lilydale Fire Station November 5th 2013 7-8:30pm

Coordinated by Peter Middleton – Coordinator Bushfire Ready Neighbourhoods Program.

Attendance:

3 senior Lilydale Fire Volunteers

5 residents

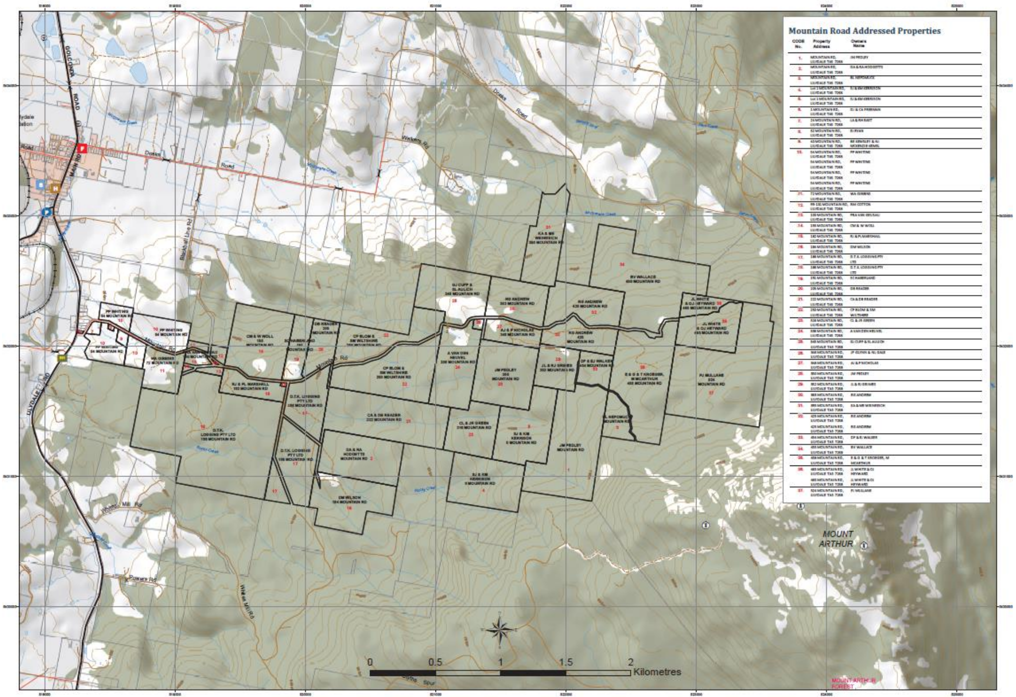


Figure 70: Location Map for Lilydale Properties involved in Community Consultation for Bushfire Ready Neighborhood's Training

Meeting Agenda

1. Peter Middleton Presented spoke the introduction and agenda,
2. Moved to table which showed the Bushfire likelihood layer,
3. Zoomed to the local region of the group attending the meeting – to speak generally about the region including treats
4. Individual examples – presented by me
5. Ended with recap of threats to general area
6. Ended with A& A
7. Break for tea/coffee with biscuits – all free to use the table individually and talk one-on-one with presenters

The touch table was the focal point of the discussion. The presenters were constantly using the table during the presentation, continuing to do so at the same rate during discussions with the group – discussing specific examples.

The touch table was controlled by the presenters until the presentation was complete then the residents started to interact with the table to use it to enhance their explanation or to show the example, as shown in Figure 71 below.

Figure 71: TasFire Bushfire Preparedness Training at Lilydale Fire Station

The touch table and the house object were used as focus points for discussion. The table allowed specific and relevant examples of potential bushfire scenarios for the region to be shown and explained in content that directly related to the participants. Five properties were preselected as examples. The defendable zones were calculated then displayed on the touch table using the house object.

When person picked up the house, focus moved to them. Some use the house as a speaking talisman – hey I am talking now.
The bushfire lessons/teachings were delivered by the presenters but while simultaneously using the table to show the impact/effect in content to the resident's landscape and houses – A process only possible because of the Tui/touch table.

Example of Typical use by the resident:

> 'What about my house? I have been clearing the scrub to the south and west – points to the area on the surface (which is clearly visible on the imagery)-'

The touch table contained the Bushfire Risk Assessment Methodology (BRAM) (Figure 72) likelihood layer with properties labeled with addresses, a layer with the zone boundaries of selected properties, background is an air photo.

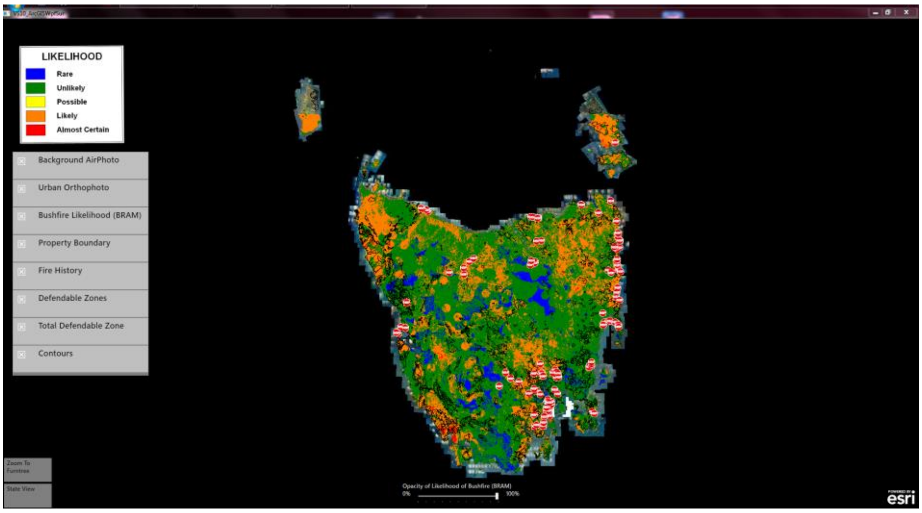


Figure 72: Screen image of the touch table showing BRAM at state scale.

Comments about Attendees

'The people we want to reach are the ones who do not attend the meetings' Lilydale Fire Chief

Are these meetings preaching to the converted?

Findings:

Many residents had never previously seen their property from an air photograph – despite the function being readily available on Google Earth. (accessed from phones, tablets, computers)

Recommendations for enhancement:

1. Add in topographical layer for navigation.
2. Add in contours,
3. Add a compass,
4. Soil moisture Index,
5. Soil Dryness Index – updated daily,
6. Perhaps include clipboard function as a future feature.
7. Calculate the zones for most properties – not just a sample

Participant Preferences

Residents liked:

- the slider for bushfire likelihood,
- the large screen,
- the house,
- the horizontal orientation.

Fire Brigade Staff liked:

- The virtual mapping features and
- 'You could view the area at regional, local and property level'

Sample Scenario from participant: general public 'I do not want to live in the city. I want to live in the beautiful countryside, have some bush around me and a view (of the mountains), but close enough to the city so that I can still have access to everything I need'.

Running Script

'State natural resource issues that directly affect people – people have their own problems.

Better understanding of how changes in one natural resource affect others in interesting and unique ways. Changes in vegetation has flow on effects to the environment also to fire safety in a peri-urban

Typical approach to acquaint people with issues is to blanket with many different new and appealing technology. Fire use pamphlets, web, posters, one-on-on Q&A, offer of personal assistance (one-on-one property assessment),'

Impact

Individual use or co-located use, reinforces the messages from the presenters.

Appendix 3 - Lorinna Bushfire Preparedness Education Meeting Summary and Results

16/11/2013 3-5pm

Coordinated by Peter Middleton, Community Development Officer
Community Education, Tasmania Fire Service

Attendees:

2 Senior Lorinna Fire Volunteers –Chief Howard, Billy Jean,

26 residents plus one dog

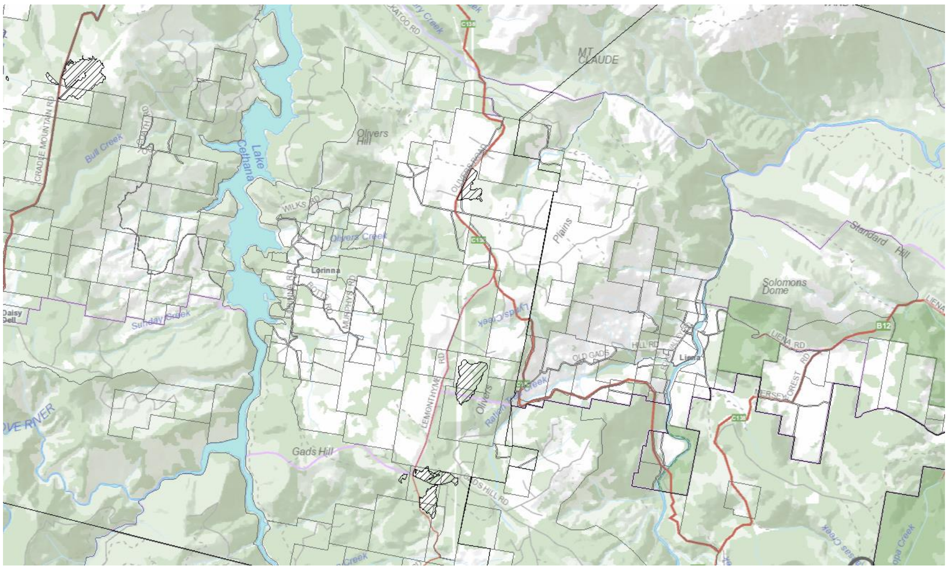


Figure 73: Lorinna region bushfire preparedness pilot area.

Location:

Lorinna (Figure 1) is an isolated community at high risk in a bushfire because of the limitations for access to the township, specifically a one lane 20km speed limited dirt road (Figure 74). For this reason Lorinna is a BioRisk area specifically targeted for bushfire education by the Tasmanian Fire Service (TFS).

Figure 74: The only road into and out of Lorinna

Lorinna appeared to have a strong sense of community. Many of the residents knew each other by name and knew exactly where one another lived along with details of their property. They have no local shop or service station. They create their own power through solar panels or mini-hydro schemes. A number owned electric cars or electric quad bikes. Many walked to the meeting in the community hall.

Background from 2012 meeting

45 attended 2012 meeting.

Tasfire undertook 20-25 property assessments with residents after the 2012 meeting. What did those present who participated in the creation of a property assessment think of the assessment process?

- 'The plans were valuable because they made you think'
- 'We bought the water tank for the community hall directly because of the assessment process. We still have not installed it yet.' ('but little steps that count. It is a need to get started.' Comment from TFS).

Schedule for equipment setup and removal

Leave Launceston at 12pm. Arrived at 2pm to setup, meeting Started at 3pm – finished at 5:15, followed by BBQ. Packed – ready to leave at 7pm.

Agenda

- Introduction by TasFIre
- Overview of expected Summer weather,
- Overview of potential impacts on the local community,
- Presentation of the Bushfire preparation Steps

- Break into two groups. One group uses the TUI, the other undertakes a simulation run by TasFIre Community Officer outside,
- Groups swap over,
- Meet together to review the day.

TasFire Presentation Summary

- Only 5-6 present have started, or completed, a written plan.
- In line with the state average – 9% have a written plan.
- Embers started the Dunalley fire. Embers travel 6-20 km.
- Residents should leave the area on a Severe or higher fire warning day. These should only occur 2 days per summer.

Tangible Touch Table Activity

Main points:

- Generated discussion around the table between neighbours and discussion for individual owners.
- Residents panned across the map from their house/area to the safe areas.
- Residents liked that they were able to visually view their escape route to the safe areas.
- The out of date imagery (2008) prompted discussion of what preparations need to be undertaken and conversely what preparation work has already been undertaken.

Feedback from Residents:

- Imagery does not show blackberries, ferns or bracken.
- Would be beneficial to show fuel load.
- Include Topography or road names
- Ability to switch to Google maps
- Add in water sources
- Include Wind
- Create a simulation animation that shows a bushfire approaching then entering the local region, show the progression of the fire through the local region. Preferably in 3d so that the impact of slope is clearly demonstrated. Match the fire progress to a time scale that is adjustable (slider for faster, slower, pause)

Results

13 residents filled out questionnaires on the day.

Q1 To what degree do you feel that the interactive surface table contributed to the meeting?

It was Detrimental	Not much	Reasonably	High level	Essential
0	0	4	6	3

Q2 How useful and engaging was using a model house to display the defendable zones?

Not at all	Some	Reasonably	Very	Ideally Suited

0	0	3	3	7

Q3 What was the most valuable feature of the Interactive Table system?

Comment	Frequency
Air Photo of the Community (big picture)	5
Visualising what to clear	4
Defendable zones	3

Q4 How well do you believe that the interactive surface table suited the purpose?

Not at all	Some	Reasonably	Very	Ideally Suited
0	1	1	4	7

Q5 Do you believe that you learnt something about preparing for a bushfire from using the interactive surface combined with the presentation by the Tasmanian Fire Officers?

No	May be	Yes
0	2	11

Q6 Did this experience inspire or motivate you to undertake preparations in case of bushfire?

No	May be	Yes
0	2	11

Q7 How familiar do you consider yourself with touch technology (smart phones, tablets, etc)?

Not at all	Little experience	Somewhat Familiar	Reasonably familiar	Very Familiar
2	0	3	3	5

Q8 What do you suggest would improve the interactive system?

Comment	Frequency
Add up to date maps or better images	7
No Comment	3

Q9 Taking into account your previous answers, please provide additional feedback that you feel may be relevant.

Comment

I would have appreciated additional input from Mark - the facilitator of the touch table.

Thank you for the work you are doing

Constant reminders and new information regulation/experiences always help

The BCA now demands that all new housing and extensions have a BAL assessment (Bushfire Attack Level)

Setup Issues

Lighting was initially an issue with false touches, however a change of location to a darker area with no reflection from white surfaces solved the problem.

Considerations

The residents in BioRisk areas –

A BioRisk area is a community with limitations to access - most likely from environmental factors such as topographic relief. These regions are higher risk than other peri-urban residents because of the high risks in evacuating the area. Residents run the risk of being cut off. Therefore these residents may have a higher uptake than residents in lower risk areas.

Appendix 4 - Ferntree Bushfire Preparedness Education Meeting Summary and Results

Meeting One: 18/12/2013 7:30-10pm

Coordinated by Peter Middleton, Community Development Officer Community Education, Tasmania Fire Service & Terry Gill Regional TFS Group Coordinator Volunteer

Attendees:

Peter Middleton, Terry Gill, Mark Brown Coordinators

11 residents

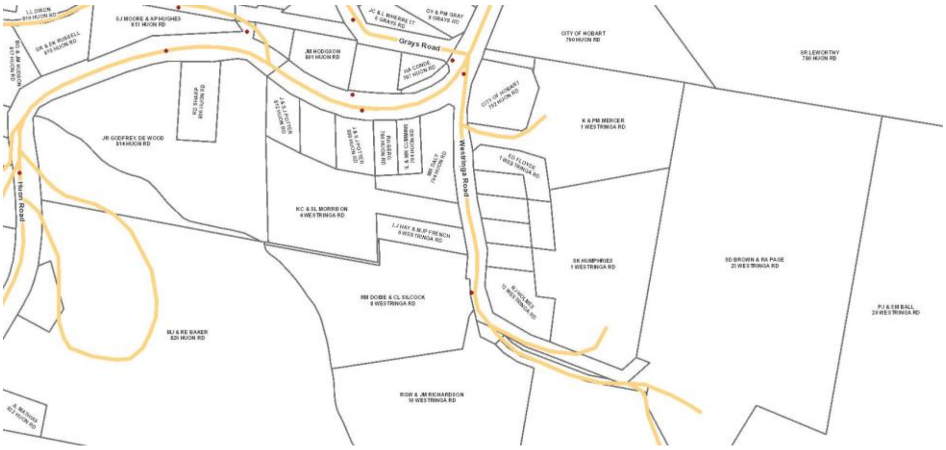


Figure 75: Ferntree WestRinga Road bushfire preparedness Group

Location:

Ferntree Westringa Rd Bushfire Preparedness Group (Figure 1) is one of the groups within the Hobart suburb of Ferntree. Houses in this area live in close proximity to one another in groups of 10 – 20 houses. The properties are surrounded by thick continuous vegetation, which was completely burn out in the 1967 bushfires. Residents are showered by embers when fires occur with the region because of the nature of the wind flow. The main road is windy single road with double wgite line. the only road in and out. Ferntree is considered at high risk in a bushfire because of the limitations for access to the residents and the surrounding vegetation. For this reason Ferntree is a BioRisk area specifically targeted for bushfire education by the Tasmanian Fire Service (TFS).

Actions:

Add extra layers:

1. Create PDF to send to Richard,
2. Fire Trails,
3. Water Tanks,

Create

1. Outer boundary for the whole community – need Richard's buildings, plus extra sheds
2. Boundaries for the neighbouring communities
3. Individual property zones using slope criteria

Other

1. Add Richard's House from the more recent imagery (Downloads from internet)
2. Create Richards House Boundary
3. Email Rachael for her completed questionnaire,
4. Write about the differences between the three regions – density of properties, likelihood of fire. Increase in participation.
5. Get Building layer from theLIST – look at metadata for age of the data layer.
6. BAL – Bushfire Attack Level

Meeting Two: 12/2/2014 7:30-10pm

9 members in attendance

Facilitated by & Terry Gill Regional TFS Group Coordinator Volunteer

This meeting was scheduled to demonstrate the recommendations made by the residents for the advancement of the *Preparing for Bushfire* Tangible Touch Table system. The recommendations included updating the aerial imagery, creating a single defendable zones boundary for the community speaker series for the of the meeting 'Always clearing – all year around'

'Always clearing – all year around'

Unequivocal belief in Bushfire. They have regular nearby bushfires.

Only one person in the community plans to leave and they do not attend the preparation for bushfire meetings and o not prepare. They also a property with the highest risk. 'If not prepared then go.'

Decide to stay or go, then prepare if you decide to stay.

One house has sprinklers.

Fully committed to staying. Community contains retired fire fighters and volunteer fire fighters.

Modify the map to add scalebar and compass, Add water layer and hydrants.

Recalc nearest safest places for Ferntree using the rules in the pamphlet. – Pamphlet may be online.

Provide PDF with ability to turn layers on and off by next week.

Read and action all emails from Robert.

Consider highlighting roads out when people ask.

Look at the online Community Plans.

Recommend for Public Education

No 1 Plan is the most important – unanimous. is decide on a plan then make sure everyone in the house knows it WELL.

Inner and outer Defensive Zones.

Colour code the Defensive Zones – watch colour rating change from red to green.

Show what point is safe as colour changes form Red to Green.

Use colour to indicate which bits need attention.

Provide photos to show canopy and understory.

- Use photos of
  Open Forest
- Shrub
- Cleared Area

Use example with two house simultaneously try to get participants to work out that they need to collaborate.

Appendix 5 - Meeting with Community Protection Planning and State Fire Management Council Hobart

6th May 2014 11:30-12:30

Background:

Following on from the Bushfire Ready Neighbourhoods Advisory Committee meeting on Monday recommend gaining further input from Community Protection Planning and the State Fire Management Council.

Attendees:

Mark Brown - UTAS PhD Student,

Peter Middleton - Community Development Officer Community Education

Chris Collins - Community Protection Planning

Sam Fergusson - State Fire Management Council

Agenda

Review spatial datasets used on the touch table displayed to the public.

Minutes/Notes

Sam – What data sets do you use, why and how?

Mark – Property Boundaries, Contours, Imagery, Fire history.

<Discussion about scale, currency, source of data, including options when table system uses internet live data compared with static local stored datasets. >

Chris: What other layers would you like?

Mark – Building footprints, Fire hydrants.

Chris – Fire hydrants layer is from Southern Water and is not spatially accurate. Building footprints are rare and not maintained.

Mark – I would like to use a Topographical layer for Navigation. Which scale do you recommend.

Chris and Sam – 250 000 top should be sufficient as a map layer.
Chris – Would Community Plan Extents be useful?
Mark – Possibly. No one has asked about them yet.

Chris – how do you use BRAMS?
Mark – I use the BRAMS Likelihood layer only.
Chris – I feel more comfortable knowing that you are only using the Likelihood layer. I would like it to cut out at a minimum zoom level.
Mark – Ok. Which scale?
Sam – I will play around with the scale and let you know.
Chris – Would it help to replace BRAMs with 'Bushfire Prone Areas Mapping'?
Mark – Yes that would help greatly.

Chris – What are your plans with this system in the future?
Mark - To use at a couple of libraries and some more community groups before the end of June.
I would like to focus upon only two educational points – make a Bushfire Plan and Defendable Spaces.
Chris – I like the idea of going to the libraries. I think that your suggestion to focus on only a couple of concepts is fair and reasonable.
Sam – [nod of assertion] I also agree with your choice of topics. Peter?
Peter Middleton – I believe there is a lot of benefit to talk about defendable spaces. That has been clearly demonstrated in the community groups that Mark and I have visited.

[General discussion about using the table as a standalone unsupervised system.
Sam stated that he was aware that touch tables are purposely designed for standalone unsupervised use – simply walk up and use - , where autonomous (passive self monitoring/controlling) modules were activated. The committee expressed their apprehension]
Sam – 'I do not believe that it will be effective when used unsupervised' (Chris agreed).
Chris – 'The education itself needs someone there to interpret and explain'
Chris – 'Lots more value by interaction and Q & A immediately'
[Sam and Chris no not recommend using 'autonomous' modules about *Preparing for Bushfire* on the table BECAUSE there is no check – 100% verification – that the subject matter is understood correctly by those who use it. The unanimous preference is an instructor lead system]

Recommendations –

1. Use Bing imagery rather than theLIST Imagery for up to date images, or Google imagery.
2. There should not be an license issue using Google imagery - Investigate
3. A Web service exists for Google earth for DPIPWE - Investigate
4. Try ESRI World Imagery service
5. Use 250k Topo for Navigation layer
6. Use 'Bushfire Prone Areas Mapping' from theLIST. (To be available imminently)
7. Do not use autonomous modules without an instructor present.

Actions – Disable BRAMS at community scale. TFS will advise precisely which scale to stop the zoom.

Update – 9th MAY 2014

Disable BRAMS at 1:100 000 scale

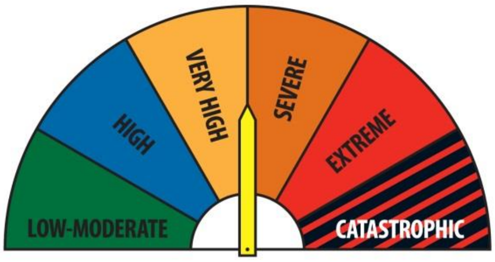
Appendix 6 - General Public Pilot Exercise at Kingston Running Script

Preparing for Bushfire Running Script

1. Fire Danger Rating
2. Preparing a bushfire plan
3. NSP
4. Requirements to prepare homes for bushfire

Fire Danger Rating

Show image of FDR



Posted on Tas fire website and on ABC radio.

Residents are instructed that their safest option for survival is leaving early when the rating is Extreme or Catastrophic.

If Sever, then may reasonably stay and defend your home If:

- ✓ your home is well prepared for bushfire and
- ✓ you are physically fit and
- ✓ you are emotionally prepared to defend your home in the face of bushfire.

Leaving Early is always the safest option. Leaving early means leaving hours before possible arrival of bushfire.

Preparing a bushfire plan

Decide what you are going to do in the event of a bushfire. Two options: Leave Early or Stay and defend your home.
If you decide to stay, then you need to prepare your home for bushfire.
Important all members of the household knows the plan and knows the steps of the plan.

Do not flee a fire at the last minute because most people who die in a bushfire are caught in the open, many are killed or injured because of poor visibility. There is no guarantee that the escape path is clear. Trees may have fallen and blocked the road while smoke may obscure visibility.

'Leaving early means leaving many hours before possible arrival of bushfire. Take:
Spare clothes, money & credit card, water, insurance policies, photo albums.
Plan to return home as soon as save to do so. Many homes initially survive and do not catch fire for several hours after the bushfire has passed.' http://www.youtube.com/watch?v=ZEORhTi9Fe4

NSP

'Identify safer places that you can relocate to at very short notice if all else fails .

- Be well prepared neighbour's house,
- sports ground,
- ploughed paddock, or
- beach. 'http://www.youtube.com/watch?v=ZEORhTi9Fe4

Your community may have identified a nearby safe place. Tasfire has identified some nearby safe places on the Community Bushfire Plan for the Tinderbox, or plan for Conningham. Note **Conningham Beach is deemed not a safe place** because the vegetation is too close to the beach.

Requirements to Prepare Homes for Bushfire

'Creating a defendable space around your home is the most important task when preparing your home for bushfires. This area must be largely free of flammable material for flames and falling embers to ignite.' Defendable space includes and inner zone where flammable material is minimised and outer with low level of flammable material'

The inner zone should be about 20m wide on flat ground.

- ☐ Relocate woodpiles away from the home
- ☐ Prune lower branches of trees
- ☐ Selectively remove trees to trap embers
- ☐ Remove flammable shrubs
- ☐ Rake bark and leaves from around buildings
- ☐ Clean gutters

Outer zone should be 15m on flat forested land and be 50m wide on steep. Guides on website.

Sometimes the state of your neighbour's property will determine whether your home can be defended in a bushfire.

Appendix 7 – Questionnaire for General Public Trial at Kingston Shopping Centre

Interactive Surfaces Stage 3 - Table

Questionnaire – Tasmania Region

Participant ID: _______________ Group:______________ Male ☐

Female ☐

Q1 What is your postcode ☐

Q2 Do you believe there is a bushfire risk where you live?

○ Yes ○ No

Q3 How vulnerable do you feel about the possibility of a bushfire affecting you, your family, or property?

1 - Not at all vulnerable	2	3	4	5 - Highly vulnerable

Q4 How prepared do you feel you are for a potential bushfire event?

1 - Not prepared at all	2	3	4	5 - Highly prepared

Q5 Do you have a written Bushfire Survival Plan?

○ No ○ Yes

Q6 How informed do you feel about your bushfire risk?

1 - Not at all	2	3	4	5 - Highly Informed

PRE-TEST

Q8 Are you aware of the term Defendable Space, if so what does I mean to you?

Comment:

____

Q9a What is the most important task when preparing your property for bushfire?

Comment:

____

Q10a When should you start to prepare your property for bushfire?

- ☐ Any time of year
- ☐ November - At the start of Summer
- ☐ January
- ☐ When the grass is really dry

Property

Boundary

INTERIM TEST

Q9b What is the most important task when preparing your property for bushfire?

Comment:

____

Q10b When should you start to prepare your property for bushfire?

- ☐ Any time of year
- ☐ November - At the start of Summer
- ☐ January
- ☐ When the grass is really dry

Q11b What inner distance should you prepare a defensive zone around your house if you live on relatively flat land in a forested area?

☐	☐	☐	☐	☐
Not Sure	10m	20m	35m	Up to

your

Property

Boundary

Q12b What outer distance should you prepare a defensive zone around your house if you live on steep land in a forested area?

☐	☐	☐	☐	☐
Not Sure	20m	35m	50m	Up to your Property Boundary

Practical EXAMPLES

Scenario 1 – Ideal

Scenario 2 – Side of the Hill

Scenario 3 – Close neighbours sharing inner zone

Q13 What actions do you recommend to prepare this property for bushfire?

Q14 What is the greatest danger to the property?

POST TEST

Q9c What is the most important task when preparing your property for bushfire?

Comment:

____

Q10c When should you start to prepare your property for bushfire?

- ☐ Any time of year
- ☐ November - At the start of Summer
- ☐ January
- ☐ When the grass is really dry

Q11c What inner distance should you prepare a defensive zone around your house if you live on relatively flat land in a forested area?

☐	☐	☐	☐	☐
Not Sure	10m	20m	35m	Up to your Property Boundary

Q12c What outer distance should you prepare a defensive zone around your house if you live on steep land in a forested area?

☐	☐	☐	☐	☐
Not Sure	20m	35m	50m	Up to your Property Boundary

Practical EXAMPLES

Scenario 4 – Single house surrounded by trees in inner zone

Scenario 5 – Bottom of the Hill

Scenario 6 – Close neighbours sharing outer zone

Q13 What actions do you recommend to prepare this property for bushfire?

Q14 What is the greatest danger to the property?

REVIEW

Learning

Q18 Do you believe that you learnt something about preparing for a bushfire from using the interactive surface with the objects?

☐ No

☐ May be

☐ Yes

Q19. Did this experience inspire or motivate you to undertake preparations in case of bushfire? Do you intend to become more prepared for a bushfire as a result of the experience using the touch table system?

☐	☐	☐
No	May be	Yes

Interface design components

Q20 How beneficial is using recent aerial photography of the local region for the examples?

☐	☐	☐	☐	☐
Not at all	Little	Reasonably	Very	Essential

Learning

Q21 How much did the Interactive Mapping help you to understand the concepts of Preparing for Bushfire?

☐	☐	☐	☐	☐
It was Detrimental	Not much	Reasonably	High level	Essential

Collaboration

Q23 Did using the Interactive Table system influence discussion or interplay between group members?

☐	☐	☐
No	May be	Yes

Interface Design

Q24 What is your impression of using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?

Comments:______ ____

Engagement

Q25 How engaging was using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?

☐	☐	☐	☐	☐
Not at all		Reasonably		Very

highly

Q26 How engaging was using Interactive Mapping on the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very

highly

Q27 How engaging was using recent aerial photography of the local region with the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very

highly

Flow

Q28 Using physical objects on the touch table was inherently interesting

☐ ☐ ☐ ☐ ☐

Strongly Disagree Strongly

Agree

Q29 Interacting with physical objects on the touch table engaged my imagination

☐ ☐ ☐ ☐ ☐

Strongly Disagree Strongly

Agree

Q30 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I thought about other things.

☐ ☐ ☐ ☐ ☐

Strongly Disagree Strongly

Agree

Q31 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I was aware of distractions

☐ ☐ ☐ ☐ ☐

Strongly Disagree Strongly

Agree

Q32 When using physical objects on the touch table with the Interactive Mapping with local recent air photography, I was totally absorbed in what I was doing

☐ ☐ ☐ ☐ ☐

Strongly Disagree Strongly Agree

Overall Design

Q33 What aspect of the experience was most memorable?

Comments:_______ ____

This exercise comprised two sections – an educational video and a interactive touch table session.

Q34 What aspects did you like about each section?

Comments:_______ ____

Q35 Which did you prefer?

☐ ☐ ☐

Video Section Interactive Table Section? No preference

Comments:_______ ____

Q36: Did you feel like the touch table environment helped to you to learn about Preparing for Bushfire?

☐ ☐ ☐

Yes May be No

Comments:_______ ____

Q37 In what way did the experience as a whole help you understand the concepts of Preparing for Bushfire? (e.g. Do you believe that you learnt more from one section than the other? Was the order of events a factor? etc)

Comments:________________________________ ____

Novelty – experience with touch

Q34 How familiar do you consider yourself with touch technology (smart phones, tablets, etc)?

☐ ☐ ☐ ☐ ☐

Not at all   Very

Familiar

Q35 Taking into account your previous answers, please provide additional feedback that you feel may be relevant.

Comments:________________________________ ____

Q36 Would you like to be advised of the results of the study and participate in a follow survey later in the year?

☐ No	☐ May be	☐ Yes

Thank you for taking the time to complete the questionnaire. Your response is greatly appreciated.

Please return this questionnaire to:

Mark Brown

m.t.brown@utas.edu.au

Please contact Mark Brown on **0407 874 068** with any questions regarding this document.

This questionnaire/interview is part of a Interactive Surface Users Interfaces PhD which investigates the efficacy of emerging technology to raise the awareness of the complexities of natural resource issues.

Mark Brown

PhD Candidate HITLab AU

School of Engineering and ICT

University of Tasmania

Locked Bag 1359

Launceston, Tasmania 7250

This PhD is partly funded by NRM North:

Supplementary Information

Did the participant start interacting with the digital map (by navigating with their fingers) during the exercise?

Yes ☐ No ☐

MEASURES

Measures for Mechanism - Targeting general public in public spaces when they attend for a typically leisure time pursuit e.g. Library, photo exhibition in a supermarket complex.

- Count how many use system & count how many decline to use system.
- Count all that enter the room
- Measures for Mechanism - Application topic is directly relevant to local residents

In the Interactive Tasks.

Count touches of pan zoom, object touches, length of time used.((Price & Falco, 2011) references (Africano et al., 2004; Inkpen et al., 1999) Time on & off task)

Audio record:

Note key word phrases:

- Constructivist learning
- Collaboration within group
- Community collaboration

Appendix 8 – Letter of Support from Kingborough Council

Kingborough

1 April 2014

Our Ref: 5.95

Mr Mark Brown
19 Keithleigh Street
YOUNGTOWN 7249

Dear Mark

PREPARING FOR BUSHFIRE APPLICATION

On behalf of Council I wish to thank you for the time given to demonstrate the Microsoft table and your "Preparing for Bushfire" application as part of Council's Community Resilience Photographic Exhibition.

The application has great benefits to the community through its ability to detail the actions required to create the necessary inner and outer protection zones. With the added bonus of being able to use interactive tools, it has been demonstrated that community members do relate to the application and that it increases individual awareness around their susceptibility to bushfires. The supportive and complimentary comments from the community are a testament to this.

The application can also be a directed benefit to Council given the ability to view properties and make assessments as to vulnerability. It would enable Council to concentrate efforts within the community to the susceptible areas making better use of valuable resources.

I encourage you to continue the development of the application and would welcome future opportunities for you to demonstrate the application to the Kingborough community as you undertake enhancements.

I wish you every success with this valuable tool and look forward to viewing your enhancements in the near future.

Yours sincerely,

DR GRAHAM BURY
MAYOR

kingborough.tas.gov.au
Civic Centre, 15 Channel Hwy, Kingston, Tasmania 7050 Locked Bag 1, Kingston Tasmania 7050
AusDoc: DX 70854 T: (03) 6211 8200 F: (03) 6211 8211 E: kc@kingborough.tas.gov.au

Appendix 9– Questionnaire for Full General Public Exercise

Interactive Surfaces Stage 3

Questionnaire – Tasmania Region

UTAS

Participant ID: _______________ Group:______________ Male ☐

Female ☐

Q1 What is your postcode? ☐

Q2 Do you believe there is a bushfire risk where you live?

☐ Yes ☐ No

Q3 How vulnerable do you feel about the possibility of a bushfire affecting you, your family, or property?

1 - Not at all vulnerable	2	3	4	5 -Highly vulnerable

Q4 How prepared do you feel you are for a potential bushfire event?

1 - Not prepared at all	2	3	4	5 - Highly prepared

Q5 Do you have a written Bushfire Survival Plan?

☐ No ☐ Yes

Q6 How well informed do you consider yourself regarding bushfire and bushfire risk?

1 - Not at all	2	3	4	5 - Highly informed

Q7 Do you understand the term Defendable Space with regards to preparing a house for bushfire ?

☐ Yes ☐ No

PRE-TEST

Q14 When should you start to prepare your property for bushfire?

☐ Any time of year

☐ At the end of Spring

☐ January

☐ When the grass is really dry

Q15 What outer distance should you prepare a defensive zone around your house if you live on steep land in a forested area?

☐ Not sure ☐ 35m ☐ 50m ☐ 70m ☐ Up to your property boundary

Q16 The Tasmania Fire Service recommends you should plan to not defend your home when the fire danger rating exceeds which level?

☐ Very High
☐ Severe
☐ Extreme
☐ Catastrophic

Practical Scenarios

Scenario 1

Scenario 2

Scenario 3

Q11 What is the greatest danger to the property?

Q12 What actions do you recommend to prepare this property for bushfire?

Q13 In a severe bushfire event –

These images are from:

http://www.bushfireeducation.vic.edu.au/for-learners/secondary/preparing-for-bushfires/ssec-prepa-act1.html

TEST 1

Q14 When should you start to prepare your property for bushfire?

- ☐ Any time of year
- ☐ At the end of Spring
- ☐ January
- ☐ When the grass is really dry

Q15 What outer distance should you prepare a defensive zone around your house if you live on steep land in a forested area?

☐	☐	☐	☐	☐
Not sure	35m	50m	70m	Up to your property boundary

Q16 The Tasmania Fire Service recommends you should plan to not defend your home when the fire danger rating exceeds which level?

- ☐ Very High
- ☐ Severe
- ☐ Extreme
- ☐ Catastrophic

Practical Scenarios

Scenario 1

Scenario 2

Scenario 3

Q17 What is the greatest danger to the property?

Q18 What actions do you recommend to prepare this property for bushfire?

Q19 In a severe bushfire event – would you Stay or Leave if

TEST 2

Q20 What is the most important task when preparing your property for bushfire?

Comment: ____

Q21 What inner distance should you prepare a defensive zone around your house if you live on relatively flat land in a forested area?

☐ Not sure ☐ 10m ☐ 20m ☐ 35m ☐ Up to your property boundary

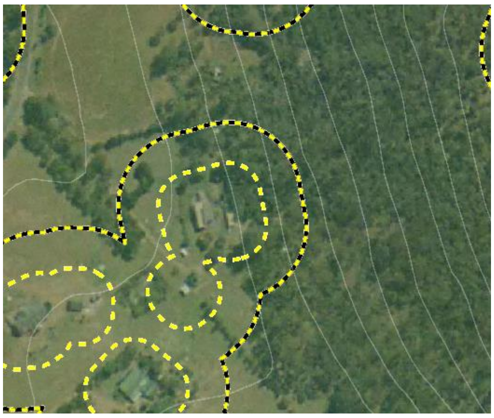
Q22 Tick the zones where the following features ideally should be present:
(Features may occur in one, both, or neither zone)

	Inner Zone	Outer Zone
Woodpile	☐	☐
Tall trees without lower limbs	☐	☐
Dam	☐	☐
Vegetable Garden	☐	☐
Small trees and shrubs	☐	☐
No trees	☐	☐

Practical Scenarios

Scenario 4

Scenario 5



Scenario 6

Q11 What is the greatest danger to the property?

Q12 What actions do you recommend to prepare this property for bushfire?

Q13 In a severe bushfire event –

REVIEW

Q26 Do you believe that you learnt something about preparing for a bushfire from using the interactive surface with the objects?

☐ No ☐ May be ☐ Yes

Q27 Did this experience inspire or motivate you to become more prepared for a bushfire as a result of the experience of using the touch table system?

☐ No ☐ May be ☐ Yes

Q28 If your prior knowledge was sufficient so that you feel you did not learn anything new - do you believe you now have a deeper understanding from this experience of using the touch table system?

☐ N/A ☐ No ☐ May be ☐ Yes

Q29 Consider how each aspect of the experience contributed to your understanding and rate according to the scale in the following table.

Contribution to Understanding

Feature	**Not at all**	**Low level**	**Reasonably**	**High level**	**Essential**
The video					
Being able to see the houses in the landscape on the aerial photo					
Using the house, rake and chainsaw to interact with the table					
Being able move around the map					
Seeing the defendable zones on the map					
The size of the display screen					
The examples with Static Maps					
The worked examples on the Interactive Map					
The experience as a whole					
The test questions					
The touch table					

Q30 How beneficial is using recent aerial photography of the local region for the examples?

☐ Not at all ☐ Slightly ☐ Reasonably ☐ Very ☐ Essential

Q31 Did the Interactive Map worked examples offer more benefits than the non-Interactive Map worked examples?

☐ Yes ☐ No

Collaboration

Q32 Did using the Interactive Table system influence discussion or interplay between group members?

☐ N/A ☐ Yes ☐ Somewhat ☐ No

Interface Design

Q33 What is your impression of using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?

Comments:____

____

Engagement

Q34 How engaging was using physical objects such as the house, rake and chainsaw to interact with the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Q35 How engaging was using Interactive Mapping on the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Q36 How engaging was using recent aerial photography of the local region with the touch table to learn about Preparing for Bushfire?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Q37 Using physical objects on the touch table was inherently interesting

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q38 Interacting with physical objects on the touch table engaged my imagination

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q39 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I thought about other things I could be doing right now.

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q40 When using the physical objects on the touch table with the Interactive Mapping with local recent air photography, I was aware of distractions

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q41 When using physical objects on the touch table with the Interactive Mapping with local recent air photography, I was totally absorbed in what I was doing

☐ ☐ ☐ ☐ ☐

Strongly disagree Strongly agree

Q42 To what degree do you believe using models (chainsaw, rake, house) helped focus your attention to the task?

☐ ☐ ☐ ☐ ☐

Not at all Reasonably Very high

Comments:____

Overall Design

Q43 What aspect of the experience was most memorable?

Comments:____

____

Q44 Would you recommend this system to others?

☐ No ☐ Yes

Q45 How familiar do you consider yourself with touch technology (smart phones, tablets, etc)?

☐ ☐ ☐ ☐ ☐

Not at all Very familiar

Q46 Taking into account your previous answers, please provide additional feedback that you feel may be relevant.

Comments:____

____

Q47 Would you like to be advised of the results of the study and participate in a follow-up survey later in the year?

☐ No ☐ May be ☐ Yes

Email:____

Thank you for taking the time to complete the questionnaire. Your response is greatly appreciated.

Please return this questionnaire to:

Mark Brown

m.t.brown@utas.edu.au

Please contact Mark Brown on **0407 874 068** with any questions regarding this document.

This questionnaire/interview is part of a Interactive Surface Users Interfaces PhD which investigates the efficacy of emerging technology to raise the awareness of the complexities of natural resource issues.

Mark Brown
PhD Candidate HITLab AU
School of Engineering and ICT
University of Tasmania
Locked Bag 1359
Launceston, Tasmania 7250

This PhD is partly funded by NRM North:

Bibliography

Anderson, L.W. et al., 2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives,(Abridged Edition)* L. W. Anderson et al., eds., Addison Wesley Longman.

Antle, A., Droumeva, M. & Ha, D., 2009. Hands on what?: comparing children's mouse-based and tangible-based interaction. *… on Interaction Design and Children*, pp.80–88.

Antle, A. & Wise, A., 2013. Getting down to details: Using theories of cognition and learning to inform tangible user interface design. *Interacting with Computers*, 25(1), pp.1–20.

Antle, A.N., Tanenbaum, J., et al., 2011. Balancing Act : Enabling Public Engagement with Sustainability Issues through a Multi-touch Tabletop Collaborative Game. *Ifip International Federation For Information Processing*, pp.194–211.

Antle, A.N., Bevans, A., et al., 2011. Futura : Design for Collaborative Learning and Game Play on a Multi-touch Digital Tabletop. In *GRAND Annual Conference 2010*. ACM, pp. 93–100.

Antle, A.N., 2012. Knowledge gaps in hands-on tangible interaction research. In *Proceedings of the 14th ACM international conference on Multimodal interaction - ICMI '12*. New York, New York, USA: ACM Press, pp. 233–240.

Antle, A.N., 2011. Workshop on Embodied Interaction : Theory and Practice in HCI. In *CHI 2011*. pp. 1–139.

Antle, A.N., Wise, A. & Nielsen, K., 2011. Towards Utopia: designing tangibles for learning. *International Conference on Interaction Design and Children*, 10, pp.11–20.

Australian Bureau of Statistics, 2008. Chapter - Adult literacy. *4102.0 - Australian Social Trends*. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0Chapter6102008 [Accessed December 21, 2014].

Azuma, R.T., 1997. A Survey of Augmented Reality. *In Presence: Teleoperators and Virtual Environments*, 6(4), pp.355–385.

Benyon, D., 2010. *Designing interactive systems A comprehensive guide to HCI and* *interaction design* 2nd Editio., Essex, England: Addison Wesley.

Bergstrom, D.M. et al., 2009. Indirect effects of invasive species removal devastate World Heritage Island. *Journal of Applied Ecology*, 46(1), pp.73–81.

Biggs, J., 1979. Individual differences in study processes and the quality of learning outcomes. *Higher Education*, 8(4), pp.381–394.

Billinghurst, M. & Kato, H., 2001. The MagicBook - Moving Seamlessly between Reality and Virtuality. *IEEE Computer Graphics and Applications*, (June), pp.6–8.

Billinghurst, M., Kato, H. & Myojin, S., 2009. Advanced Interaction Techniques for Augmented Reality Applications. In R. Shumaker, ed. *Virtual and Mixed Reality*. Springer Berlin / Heidelberg, pp. 13–22.

Blondy, L.C., 2007. Evaluation and Application of Andragogical Assumptions to the Adult Online Learning Environment. *Learning*, 6(2), pp.116–130.

Boylan, J., Cheek, C. & Skinner, T., 2013. *Preliminary Report on the January 2013 Fires in the South-Eastern Tasmania Research Project*, Hobart.

Brett, G. et al., 2014. *The Peeragogy Handbook Founding Editor*,

Bryant, S. & Shaw, J., 2007. *Threatened species assessment on Macquarie Island*,

Buxton, B., 2007. *Sketching User Experiences*, Elsevier.

Clements, D.H., 2000. "Concrete"Manipulatives, Concrete Ideas. *Contemporary Issues in Early Childhood*, 1(1), pp.45–60.

Costanza, E. et al., 2010. Tangible Interfaces for Download : Initial Observations from Users ' Everyday Environments. , pp.2765–2774.

Couture, N. et al., 2008. GeoTUI : A Tangible User Interface for Geoscience. In *TEI '08*. pp. 89–96.

Csíkszentmihály, M., 1997. Finding flow: the pschology of engagement with everyday life. *Psychology Today*, pp.1–7.

Cudmore, W., 2009. Illustrations of Interconnectedness in Ecosystems Author contact information. *New York*, pp.1–41.

Cuendet, S., Bumbacher, E. & Dillenbourg, P., 2012. Tangible vs. virtual representations: when tangibles benefit the training of spatial skills. *Proceedings of the 7th Nordic …*, pp.99–108.

Dahlman & Renwick, 2015. *Dahlman, Carl T, and William H Renwick. Introduction To Geography* 6th ed., Boston: Pearson Educational LtD.

Department of Sustainability, E. & Division, A.A., 2011. Lessons learned from devastating effects of cat eradication on Macquarie Island :: Australian Antarctic Division. Available at: http://www.antarctica.gov.au/media/news/2009/lessons-learned-from-devastating-effects-of-cat-eradication-on-macquarie-island [Accessed June 14, 2012].

Deterding, S. et al., 2011. From Game Design Elements to Gamefulness : Defining " Gamification ." In *Envisioning Future Media Environments*. MindTrek '11 Procceedings of the 15 International Academic MindTrek Conference, pp. 9–11.

Dourish, P., 2001. *Where the Action Is: The Foundations of Embodied Interaction*, MIT Press.

DPIPWE, 2012. Optimism for a mending Macca. *Tasmanian Regions Autumn 2012*. Available at: http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SSKA-8S55GW?open [Accessed June 14, 2012].

Duncan, R., 1995. Piaget and Vygotsky Revisited: Dialogue or Assimilation? *Developmental Review*, 15(4), pp.458–472.

Edge, D., 2008. Hands-Only Scenarios and Video Action Walls – novel methods for tangible for peripheral interaction. *Analysis*, (733).

Edge, D. & Blackwell, A., 2006. Correlates of the cognitive dimensions for tangible user interface. *Journal of Visual Languages Computing*, 17(4), pp.366–394.

Engadget, 2012. Ideum's MT65 Presenter: a $17,500, 65-inch, multi-touch display for your own museum -- Engadget. Available at: http://www.engadget.com/2012/01/17/ideums-mt65-presenter-a-17-500-65-inch-multi-touch-display/#continued [Accessed March 26, 2012].

Etemad, M.E., 1994. *The Role of Kinesthetics in Learning- The Importance of Active Engagement and the Connected Process of Reflection*,

Fernaeus, Y. & Tholander, J., 2008. Towards a new set of ideals: consequences of the practice turn in tangible interaction. *TEI '08*, pp.223–230.

Fink, L.D., 2003a. *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses*, Jossey-Bass.

Fink, L.D., 2003b. *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses*, Jossey-Bass.

Fishkin, K., 2004. A taxonomy for and analysis of tangible interfaces. *Personal and Ubiquitous Computing*, 8(5), pp.347–358.

Fitzmaurice, G., Ishii, H. & Buxton, W., 1995. Bricks: laying the foundations for graspable user interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM Press/Addison-Wesley Publishing Co., pp. 442–449.

Fitzmaurice, G.W., 1996. *GRASPABLE USER INTERFACES*.

Fleck, R. et al., 2009. Actions speak loudly with words: unpacking collaboration around the table. *ITS '09*.

Fleming, N.D., 1995. I'm different; not dumb. Modes of presentation (VARK) in the tertiary classroom. In A. Zelmer, ed. *Proceedings of the 1995 Annual Conference of the Higher Education and Research Development Society of Australasia HERDSA*. HERDSA, pp. 308–313.

Foster, C., 2008. Learning for understanding : Visualization. *Information Visualization*, pp.1–180.

Frandsen, M., 2012. *Promoting community bushfire preparedness: Bridging the theory–practice divide*. University of Tasmania.

Furness, T., 2012. Presentation to Industry showing past future projects for HITLAB.

Gage, R., 1995. Excuse me, you ' re cramping my style : Kinesthetics for the classroom. *The English Journal*, 84(8), pp.52–55.

García-Barrios, L.E., Speelman, E.N. & Pimm, M.S., 2008. An educational simulation tool for negotiating sustainable natural resource management strategies among stakeholders with conflicting interests. *Ecological Modelling*, 210(1-2), pp.115–126.

Gentile, A. et al., 2011. Human-to-human interfaces : emerging trends and challenges. *Int. J. Space-Based and Situited Computing*, 1(1), pp.3–17.

Goodgame, D. (Kimberley S., 2004. Cane Toads. Available at: http://www.canetoads.com.au/canetfact.htm [Accessed March 7, 2012].

Gorbet, M., Orth, M. & Ishii, H., 1998. Triangles: tangible interface for manipulation and exploration of digital information topography. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. pp. 49–56.

Gray, A., 1997. Constructivist Teaching and Learning. *SSTA Research Centre Report*, 7, pp.1–23.

Grose, M.R. et al., 2010. Climate Futures for Tasmania: general climate impacts technical report.

Guest, G., Bunce, A. & Johnson, L., 2006. How Many Interviews Are Enough? *Field Methods*, 18(1), pp.59–82.

Heijboer, M. & Van Den Hoven, E., 2008a. Keeping up appearances : Interpretation of tangible artifact design. *Proceedings of the 5th Nordic conference on Humancomputer interaction building bridges*, pp.162–171.

Heijboer, M. & Van Den Hoven, E., 2008b. Keeping up appearances : Interpretation of tangible artifact design. *Proceedings of the 5th Nordic conference on Humancomputer interaction building bridges*, pp.162–171.

Hodges, S. et al., 2007. ThinSight: versatile multi-touch sensing for thin form-factor displays. In *Proceedings of the 20th annual ACM symposium on User interface software and technology*. ACM, pp. 259–268.

Hoffman, D.L. & Novak, T.P., 2009a. Flow Online: Lessons Learned and Future Prospects. *Journal of Interactive Marketing*, 23(1), pp.23–34.

Hoffman, D.L. & Novak, T.P., 2009b. Flow Online: Lessons Learned and Future Prospects. *Journal of Interactive Marketing*, 23(1), pp.23–34.

Hofstra, H. et al., 2008. Multi-user tangible interfaces for effective decision-making in disaster management. *Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters*, pp.243–266.

Hollender, N. et al., 2010. Integrating cognitive load theory and concepts of human–computer interaction. *Computers in Human Behavior*, 26(6), pp.1278–1288.

Holmquist, L., Redström, J. & Ljungstrand, P., 1999. Token-based access to digital information. *Handheld and Ubiquitous …*, pp.234–245.

Horn, M.S., Crouser, R.J. & Bers, M.U., 2011a. Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing*, pp.1–11–11.

Horn, M.S., Crouser, R.J. & Bers, M.U., 2011b. Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing*, pp.1–11–11.

Hornecker, E. & Buur, J., 2006. Getting a Grip on Tangible Interaction : A Framework on

Physical Space and Social Interaction. *CHI 2006*, pp.437–446.

Van Den Hoven, E. et al., 2007. Design research & tangible interaction. *TEI 07*, p.109.

Howison, M. et al., 2011. The Mathematical Imagery Trainer : From Embodied Interaction to Conceptual Learning. *Education*, (Chi), pp.1989–1998.

HowStuffWorks, 2012. HowStuffWorks "How the First-Down Line Works." Available at: http://www.howstuffworks.com/first-down-line.htm [Accessed March 21, 2012].

HP, 2012. HP VantagePoint. Available at: http://www8.hp.com/us/en/ad/vantagepoint/form.html [Accessed March 26, 2012].

Hughes, L. & Steffen, W., 2013. *BE PREPARED : CLIMATE CHANGE AND THE AUSTRALIAN*, Climate Council.

Hutchings, J.A., 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. *Canadian Journal of Aquatic Science*, 962, pp.943–962.

Interfaces, et évaluer de nouvelles, 2012. Touch-based interfaces for Interaction with 3D Content | projet-instinct. Available at: http://anr-instinct.cap-sciences.net/?q=node/34 [Accessed March 26, 2012].

Ishii, H., 2008. Tangible bits: beyond pixels. In *Proceedings of the 2nd international conference on Tangible and embedded interaction*. ACM, pp. xv–xxv.

Ishii, H. & Ullmer, B., 1997. Tangible bits: towards seamless interfaces between people, bits and atoms. *Proceedings of the SIGCHI conference on Human factors in computing systems*, (March), p.241.

Javed, W. et al., 2011. Evaluating physical/virtual occlusion management techniques for horizontal displays. *Human-Computer Interaction–INTERACT*, pp.391–408.

Kaltenbrunner, M. et al., 2005. TUIO: A protocol for table-top tangible user interfaces. In *Proc. of the The 6th Int'l Workshop on Gesture in Human-Computer Interaction and Simulation*. Citeseer.

Kim, S. & Dey, A.K., 2010. AR interfacing with prototype 3D applications based on user-centered interactivity. *Computer-Aided Design*, 42(5), pp.373–386.

Kirk, D. et al., 2009. Putting the physical into the digital: issues in designing hybrid interactive surfaces. In *Proceedings of the 23rd British HCI Group Annual Conference* *on People and Computers: Celebrating People and Technology*. pp. 35–44.

Knowles, M.S., Holton, E.F. & Swanson, R.A., 2005. *The Adult Learner*, Butterworth-Heinemann.

Koleva, B. et al., 2003. A Framework for Tangible User Interfaces. In *Mobile HCI 2003*. Citeseer, pp. 46–50.

Kraaijenbrink, E. et al., 2009. Balancing Skills to Optimize Fun in Interactive Board Games. *Ifip International Federation For Information Processing*, pp.301–313.

van Krevelen, D.W.F. & Poelman, R., 2010. A Survey of Augmented Reality Technologies Applications and Limitations. *The International Journal of Virtual Reality*, 9(2), pp.1–20.

Kubicki, S., Lepreux, S. & Kolski, C., 2011. Evaluation of an interactive table with tangible objects : Application with children in a classroom. *CHI 2011*.

Lagi, M. & Bar-Yam, Y., 2012. UPDATE July 2012| The Food Crises: The US Drought. *arXiv preprint arXiv:1209.6376*, (July), pp.1–6.

Landauer, T.K., 1997. Behavioral research methods in human–computer interaction. In M. Helander, K. T. Landauer, & P. Prabhu, eds. *Handbook of Human–Computer Interaction*. Amsterdam, Netherlands: Elsevier, pp. 203–227.

Lindenmayer, D. & CSIRO, 2007. *On borrowed time : Australia's environmental crisis and what we must do about it* 1st ed., Camberwell, Vic, Australia: Penguin Books in association with CSIRO Publishing, Camberwell, Vic.

Lucchi, A. et al., 2010. An empirical evaluation of touch and tangible interfaces for tabletop displays. *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction - TEI '10*, pp.177–184.

Lujan, H.L. & DiCarlo, S.E., 2006a. First-year medical students prefer multiple learning styles. *Advances in Physiology Education*, 30(1), pp.13–6.

Lujan, H.L. & DiCarlo, S.E., 2006b. First-year medical students prefer multiple learning styles. *Advances in Physiology Education*, 30(1), pp.13–6.

Mackie, B., McLennan, J. & Wright, L., 2013. *COMMUNITY UNDERSTANDING AND AWARENESS OF BUSHFIRE SAFETY : JANUARY 2013 BUSHFIRES*,

Mancini, C. et al., 2010. ContraVision : Exploring Users ' Reactions to Futuristic Technology. *CHI 2010*, pp.153–162.

Marshall, P., 2007. Do tangible interfaces enhance learning? In *Proceedings of the 1st international conference on Tangible and embedded interaction - TEI '07*. New York, New York, USA: ACM Press, pp. 163–170.

Marshall, P., Cheng, P. & Luckin, R., 2010. Tangibles in the balance: a discovery learning task with physical or graphical materials. *TEI 2010*, pp.153–160.

Marshall, P., Price, S. & Rogers, Y., 2003. Conceptualising tangibles to support learning. In *Proceeding of the 2003 conference on Interaction design and children - IDC '03*. New York, New York, USA: ACM Press, pp. 101–109.

Marshall, P., Rogers, Y. & Hornecker, E., 2007. Are Tangible Interfaces Really Any Better Than Other Kinds of Interfaces ? In *CHI 2007*.

Marvell, A., 2002. Sharing Nature's Interest: Ecological Footprints as an Indicator of Sustainability / From Here to Sustainability: Politics in the Real World. *The Geographical Journal*, 168, p.272.

Mcgookin, D., Robertson, E. & Brewster, S., 2010. Clutching at Straws : Using Tangible Interaction to Provide Non-Visual Access to Graphs. In *CHI 2010*. pp. 1715–1724.

McLellan (eds), R., 2014. *The Living planet Report, 2014* WWF, ed., Gland, Switzerland: World Wide Fund for Nature.

Mendham, T., 2010. AR Eco Awareness at SEA Lab. *Not Just Reality*. Available at: http://www.notjustreality.com/lead-story/929-ar-sea-lab-la/ [Accessed April 10, 2012].

Microsoft, 2011. *Microsoft Surface 2.0 Design and Interaction Guide*,

Milgram, P. & Kishino, F., 1994. A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems*, E77-D(12), pp.1–15.

MIT Media Lab, 2012. Tangible Media | MIT Media Lab. Available at: http://www.media.mit.edu/research/groups/tangible-media [Accessed March 8, 2012].

Mitasova, H. et al., 2006. Real-time landscape model interaction using a tangible geospatial modeling environment. *Computer Graphics and Applications, IEEE*, 26(4), pp.55–63.

Novak, T.P., Hoffman, D.L. & Yung, Y.-F., 2000. Measuring the Customer Experience in Online Environments: A Structural Modeling Approach. *Marketing Science*, 19(1), pp.22–42.

NRI, 2011. Natural Resource Information. Available at: http://www.consequently.net/natural_resource/encyclopedia.htm [Accessed February 23, 2012].

O'Malley, C. & Stanton Fraser, D., 2004. Literature Review in Learning with Tangible Technologies. *Technology*, 11(2004), pp.1–52.

Oates, B.J., 2006. *Researching Information Systems and Computing*, Sage.

Oliver, K., 2009. An Investigation of Concept Mapping to Improve the Reading Comprehension of Science Texts. *Journal of Science Education and Technology*, 18(5), pp.402–414.

Ormrod, J.E., 2004. *Human Learning* A. W. Toga & J. C. Mazziotta, eds., Prentice Hall.

Ott, M. & Luderschmidt, J., 2012. Enhancing Interactive Tabletop Workspaces with Tangible Contexts. *Mensch & Computer*, pp.53–62.

Oviatt, S., 2006. Human-centered design meets cognitive load theory: designing interfaces that help people think. *Proceedings of the 14th annual ACM international conference on Multimedia*, pp.871–880.

Piaget, J., 1962. Play, dreams, and imitation in childhood (C. Gattegno & FM Hodgson, Trans.). *NY Norton*.

Pierce, D., 2011. The Perfect Babysitter: an iPad? | Digitizd. *Digitizd*. Available at: http://www.digitizd.com/2011/02/24/your-babysitter-an-ipad/ [Accessed October 31, 2015].

Piper, B., Ratti, C. & Ishii, H., 2002. Illuminating clay: a 3-D tangible interface for landscape analysis. In *Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves*. ACM, pp. 355–362.

Preece, J., Rogers, Y. & Sharp, H., 2011. *Interaction Design beyond human-computer interaction 3rd Edition*, Wiley.

Price, S., 2008a. A representation approach to conceptualizing tangible learning environments. *Proceedings of the 2nd international conference on Tangible and embedded interaction TEI 08*, p.151.

Price, S., 2008b. A representation approach to conceptualizing tangible learning environments. *Proceedings of the 2nd international conference on Tangible and* *embedded interaction TEI 08*, p.151.

Price, S., 2004. Let’s get physical: The learning benefits of interacting in digitally augmented physical spaces. *Computers & Education*, 43(1-2), pp.137–151.

Price, S. et al., 2008. Towards a framework for investigating tangible environments for learning. *International Journal of Arts and Technology*, 1(3), pp.351–368.

Price, S., Rogers, Y., Scaife, M., Stanton, D., et al., 2003. Using “Tangibles” to promote novel forms of playful learning. *Interacting with Computers*, 15(2), pp.169–185.

Price, S., Rogers, Y., Scaife, M., Stanton, D., et al., 2003. Using “Tangibles” to promote novel forms of playful learning. *Interacting with Computers*, 15(2), pp.169–185.

Price, S. & Falco, T.P., 2011a. Where the attention is: Discovery learning in novel tangible environments. *Interacting with Computers*, In Press,.

Price, S. & Falco, T.P., 2011b. Where the attention is: Discovery learning in novel tangible environments. *Interacting with Computers*, 23(5), pp.499–512.

Price, S., Sheridan, J. & Falcao, T.P., 2010. Action and representation in tangible systems: implications for design of learning interactions. In *Children*. Association for Computing Machinery, pp. 145–152.

Price, S., Sheridan, J.J. & Falcao, T.P., 2010. Action and representation in tangible systems: implications for design of learning interactions. In *TEI ’10*. Association for Computing Machinery, pp. 145–152.

Queensland/Education, 2010. Bloom’s Revised Taxonomy. Available at: http://www.kurwongbss.eq.edu.au/thinking/Bloom/blooms.htm [Accessed April 17, 2012].

Quinn, G.P. & Keough, M.J., 2002. *Experimental Design and Data Analysis for Biologists* C. U. Press, ed., Cambridge University Press.

Raffle, H. & Garcia, C., 2003. topobo for Tangible Learning. *Direct*, pp.1–7.

Raffle, H. & Garcia, C., 2003. topobo for Tangible Learning. *Direct*, pp.1–7.

Resnick, M. et al., 1998. Digital manipulatives: new toys to think with. *Communications of the ACM*, (April), pp.281–287.

Rick, J. et al., 2009. Learning by doing with shareable interfaces Learning by Doing with Shareable Interfaces. *Children, Youth and Environments*, 19(1), pp.321–342.

Robinson, K., 2010. Sir Ken Robinson: Bring on the learning revolution! | Video on TED.com. Available at: http://www.ted.com/talks/sir_ken_robinson_bring_on_the_revolution.html [Accessed June 20, 2012].

Rogers, Y. et al., 2009. *Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays?*,

Ross, P.M., Tronson, D. & Science, C., 1998. Towards conceptual understanding : bringing research findings into the lecture theatre in tertiary science teaching. *Science*, (Grinder 1988), pp.52–71.

Ryan, R.M. & Deci, E.L., 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist* , 55(1), pp.68–78.

Sauro, J. & Lewis, J., 2012a. *Quantifying the user experience: Practical statistics for user research* 1st ed., MA, USA: Morgan Kaufmann.

Sauro, J. & Lewis, J., 2012b. *Quantifying the user experience: Practical statistics for user research* 1st ed., MA, USA: Morgan Kaufmann.

Savery, J.R. & Duffy, T.M., 1995. Problem based learning: An instructional model and its constructivist framework. *Educational Technology*, 35(5), pp.31–38.

Scharf, F., Winkler, T. & Herczeg, M., 2008. Tangicons: algorithmic reasoning in a collaborative game for children in kindergarten and first class. In *Proceedings of the 7th international conference on Interaction design and children*. ACM, pp. 242–249.

Schneider, B., Jermann, P., Zufferey, G., et al., 2010. Benefits of a tangible interface for collaborative learning and interaction. *IEEE Transactions on Learning Technologies*, 4(2), pp.1–12.

Schneider, B. et al., 2013a. Preparing for Future Learning with a Tangible User Interface: The Case of Neuroscience. *IEEE Transactions on Learning Technologies*, 6(2), pp.117–129.

Schneider, B. et al., 2013b. Preparing for Future Learning with a Tangible User Interface: The Case of Neuroscience. *IEEE Transactions on Learning Technologies*, 6(2), pp.117–129.

Schneider, B., Jermann, P. & Zufferey, G., 2010. Benefits of a tangible interface for collaborative learning and interaction. *IEEE Transactions on Learning Technologies*, 4(2), pp.1–12.

Scotta, A., Pleizier, I. & Scholten, H., 2006. Tangible user interfaces in order to improve collaborative interactions and decision making. *Proceedings of 25th Urban Data*, (2).

Shaer, O. et al., 2004. The TAC paradigm: specifying tangible user interfaces. *Personal and Ubiquitous Computing*, 8(5), pp.359–369.

Shaer, O. & Hornecker, E., 2010. Tangible User Interfaces : Past Present ,and Future Directions. *HCI 09*, 3(2009), pp.1–137.

Shamonsky, D.J., 2003. *Tactile, Spatial Interfaces for Computer-Aided Design Superimposing Physical Media and Computation by*.

Shams, L. & Seitz, A.R., 2008. Benefits of multisensory learning. *Trends in cognitive sciences*, 12(11), pp.411–7.

Sharp, H., Rogers, Y. & Preece, J., 2011. *Interaction Design: Beyond Human-Computer Interaction*,

Shen, C., 2004. DiamondSpin : An Extensible Toolkit for Around-the-Table Interaction. *CHI 2004*, 6(1), pp.167–174.

Shen, C., Everitt, K. & Ryall, K., 2003. UbiTable: Impromptu face-to-face collaboration on horizontal interactive surfaces. In *UbiComp 2003: Ubiquitous Computing*. pp. 281–288.

Sherman, W.R. et al., 2007. VRFire : an Immersive Visualization Experience for Wildfire Spread Analysis. *Fuel*, pp.2007–2010.

Sokal, R.R. & Rohlf, F.J., 1995. *Biometry: the principles and practice of statistics in biological research* W. H. Freeman, ed., W. H. Freeman and Company.

Speelpenning, T. et al., 2011. Exploring How Tangible Tools Enable Collaboration in a Multi-touch Tabletop Game. *Ifip International Federation For Information Processing*, pp.605–621.

Starcic, A.I., Cotic, M. & Zajc, M., 2013. Design-based research on the use of a tangible user interface for geometry teaching in an inclusive classroom. *British Journal of Educational Technology*, 44(5), pp.729–744.

Streng, S. et al., 2009. *TRENDS IN E-LEARNING*,

Terrenghi, L. et al., 2007. Affordances for manipulation of physical versus digital media on interactive surfaces. *Proceedings of the SIGCHI conference on Human factors in* *computing systems - CHI '07*, pp.1157–1166.

Triona, L.M. & Klahr, D., 2003. Point and Click or Grab and Heft: Comparing the Influence of Physical and Virtual Instructional Materials on Elementary School Students' Ability to Design Experiments. *Cognition and Instruction*, 21(2), pp.149–173.

Tuddenham, P. & Kirk, D., 2010. Graspables revisited: multi-touch vs. tangible input for tabletop displays in acquisition and manipulation tasks. *CHI 2010*, pp.2223–2232.

Ulmer, B. & Ishii, H., 1997. The metaDESK : Modes and Prototypes for Tangible User Interfaces. In *Proceedings of the 10th annual ACM symposium on User interface software and technology*. ACM, pp. 223–232.

Uttal, D.H., Scudder, K. V & DeLoache, J.S., 1997. Manipulatives as symbols: A new perspective on the use of concrete objects to teach mathematics. *Journal of Applied Developmental Psychology*, 18(1), pp.37–54.

Di Vita, G., 2006. Natural resources dynamics: Exhaustible and renewable resources, and the rate of technical substitution. *Resources Policy*, 31(3), pp.172–182.

Wagner, D. et al., 2010. Real-time detection and tracking for augmented reality on mobile phones. *IEEE transactions on visualization and computer graphics*, 16(3), pp.355–68.

Winograd, T. & Flores, F., 1986. *Understanding Computers and Cognition: A New Foundation for Design*, Addison-Wesley.

World Commission, 1987. *Report of the World Commission on Environment and Development: Our Common Future Acronyms and Note on Terminology Chairman's Foreword*,

Wroblewski, L. et al., 2010. LukeW | Touch Gesture Reference Guide. Available at: http://www.lukew.com/ff/entry.asp?1071 [Accessed October 23, 2015].

Xie, L., Antle, A. & Motamedi, N., 2008. Are Tangibles More Fun?: comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *TEI '08*. pp. 191–198.

Zhang, J. & Norman, D.A., 1994. Representations in distributed cognitive tasks. *Cognitive science*, 18(1), pp.87–122.

Zuckerman, O., Arida, S. & Resnick, M., 2005. Extending tangible interfaces for education: digital montessori-inspired manipulatives. In *CHI '05 extended abstracts on Human factors in computing systems*. pp. 859–868.

Zuckerman, O. & Gal-Oz, A., 2013. To TUI or not to TUI: Evaluating performance and preference in tangible vs. graphical user interfaces. *International Journal of Human-Computer Studies*, 71(7-8), pp.803–820.